PALEOENVIRONMENTAL STUDIES OF THE STATE ROUTE 1 CORRIDOR: CONTEXTS FOR PREHISTORIC SETTLEMENT, NEW CASTLE AND KENT COUNTIES, DELAWARE

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ABSTRACT

Results of four environmental studies undertaken to help recreate the landscape inhabited by prehistoric people along the State Route 1 corridor are presented. The paleoenvironmental and geological studies were conducted at key locations adjacent to significant archaeological sites that will be impacted by highway construction. The introduction reviews the methods used in the studies and provides the regional paleoenvironmental context. Pollen and hydrological studies of bay/basin ponds show that climate was extremely dry in central Delaware between approximately 11,000 and 6000 years ago. Geological investigations of wetlands in streams valleys adjacent to archaeological sites show the impacts of changing stream flow and relative sea-level rise on wetland environments. Analysis of the pollen and seed contents of cores taken in the wetlands show changes in local environments, climate, and potential food resources. The conclusions discuss the implications of the studies for interpreting how people lived in central Delaware in prehistoric times.

DelDOT Archaeological Series Index Information

This form is intended to provide information on the contents of this volume for indexing. It is also intended for researchers to use to check the research methods and topics included in this volume.

Report Title: **PALEOENVIRONMENTAL STUDIES OF THE STATE ROUTE 1 CORRIDOR: CONTEXTS FOR PREHISTORIC SETTLEMENT, NEW CASTLE AND KENT COUNTIES, DELAWARE**

DelDOT Report Number: **114**

Level of Investigations: [Phase I, II, III, Planning Survey, Specialized Study]

SPECIALIZED STUDY

Basic Time Periods Covered:

__X__ All prehistoric
_____ Mainly prehistoric, some historic
_____ Equal coverage of prehistoric and historic
_____ Mainly historic, some prehistoric
_____ All historic

Site Contexts: **NOT APPLICABLE**

	Prehistoric	Historic
Plow zone/disturbed surface soils	**NOT APPLICABLE**	**NOT APPLICABLE**
Intact features	**NOT APPLICABLE**	**NOT APPLICABLE**
Buried artifact-bearing strata	**NOT APPLICABLE**	**NOT APPLICABLE**

List up to five major time periods or site types

1. **ALL PREHISTORIC TIME PERIODS**

List up to eight major topics covered in Conclusions and Discussions of Results

1. **BAY/BASIN FEATURES**
2. **REGIONAL CLIMATE**
3. **LOCAL ENVIRONMENTS**
4. **SEA LEVEL RISE**
5. **REGIONAL SETTLEMENT PATTERNS**

Specialized Analyses Undertaken

	Prehistoric	Historic
Blood Residue		
Ceramic Chronology		
Ceramic Vessel Surface Alterations		
Cordage Twists from Ceramic Impressions		
Faunal Analysis		
Flake Attributes		
Floral Analysis	**X**	
Flotation	**X**	
Geomorphology and Pedology	**X**	
Glass Analysis		
HABS Documentation		
HAER Documentation		
Historic Architecture		
Informant Interviews		
Leather Analysis		
Miller Ceramic Index		
Mortar Analysis		
Palynology	**X**	
Projectile Point Chronology		
Projectile Point Function		
Radiocarbon Dates	**X**	
Soil Chemistry		
Spatial Distribution of Artifacts		
Stone Tool Functional Analysis		
Wood Identification	**X**	

List up to 5 other specialized analyses not listed above:

NOT APPLICABLE

Geographic Area Covered

__X__ New Castle County
__X__ Kent County
_____ Sussex County
_____ All State

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Cover Illustration: Map showing present climate zones in Eastern North America. The zones are identified by the dominant air masses that determine weather. The Delmarva Penninsula is in a transition zone, thus our weather is highly variable and susceptible to climate change.

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INTRODUCTION

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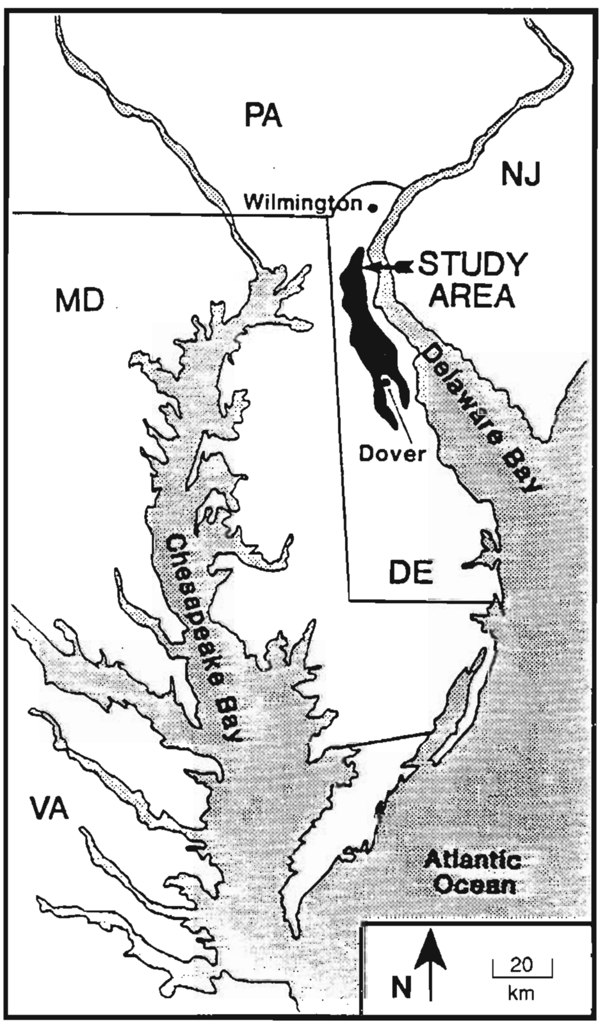
FIGURE 1
Location of State Route 1 Study Area



This report presents the results of research on past environments near archaeological sites discovered along the State Route 1 corridor (formerly designated U.S. Route 13) in New Castle and Kent counties, Delaware (Figure 1). From studies throughout the mid-Atlantic region it is known that the environments of Delaware have changed dramatically in the past (Custer 1984a:30-37; 1989). However, we do not always know what environments existed at particular places at particular times in the past. The studies included in this report provide specific information on past environments at, or near, prehistoric archaeological sites in the State Route 1 corridor. Environmental studies are important to prehistoric archaeology because almost all of Delaware's prehistoric inhabitants survived by hunting and gathering. Agriculture was not practiced until just before European colonization, so earlier people had to rely on whatever plant and animal foods could be found in the natural environment around them. If we know what kinds of resources were available in the past, then we can better understand how prehistoric people lived.

Research of past environments involves technical studies of geological and fossil evidence, such as stream and pond sediments, soils, and plant fragments and pollen. The four reports presented here provide the technical information necessary to recreate past environments in Delaware. The technical reports follow a summary of the State Route 1 archaeological project, a discussion of the methods used to study past environments, and a review of Delaware's prehistory. A synthesis of the technical studies which discusses their implications for archaeological studies of the State Route 1 corridor concludes the volume.

THE STATE ROUTE 1 PROJECT

Archaeological research into the history and prehistory of the State Route 1 corridor in Delaware began in 1982 with the preparation of a reconnaissance and planning study of a large area within which the new highway would be constructed (Custer et al. 1984). The purpose of the study was to identify and tabulate known cultural resources including historic buildings, historic archaeological sites of Delaware's early settlers, and prehistoric Native American archaeological sites that might be disturbed by highway construction. The study also used Landsat satellite photography to identify areas that were likely site locations, but had never been examined for archaeological sites (Custer Bachman, and Grettler 1986). The study was undertaken because cultural resources are protected by law under Section 106 of the National Historic Preservation Act. Archaeological research is one of the activities included in the preparation of any environmental impact statements for federally funded projects (for example, Custer and Cunningham 1986). The reconnaissance and planning survey of the State Route 1 corridor documented 150 prehistoric sites and over 750 historic sites.

After the initial planning study, more specific and detailed archaeological research was undertaken in selected areas of the highway corridor where the earlier study had indicated high densities of sites and a high potential for additional archaeological sites (Custer and Bachman 1986a; Custer, Bachman, and Grettler 1986). The study documented the relationships between archaeological sites and environmental variables in an effort to better understand patterns of prehistoric land use. For example, 90% of all prehistoric sites in the project area are within 100 m (328 ft.) of water (Custer and Bachman 1986a:131). In contrast, only half of the historic sites in the project area are within 200 m (660 ft.) of fresh water (Custer and Bachman 1986a:173). Field survey located 425 new (previously unrecorded) prehistoric archaeological sites and tests of the predictive model showed that it worked well (Custer, Bachman, and Grettler 1986:175). The studies by Newby, Webb, and Webb, reported here, were initiated during this phase of research (Bachman 1987:100; Custer and Bachman 1986a:83).

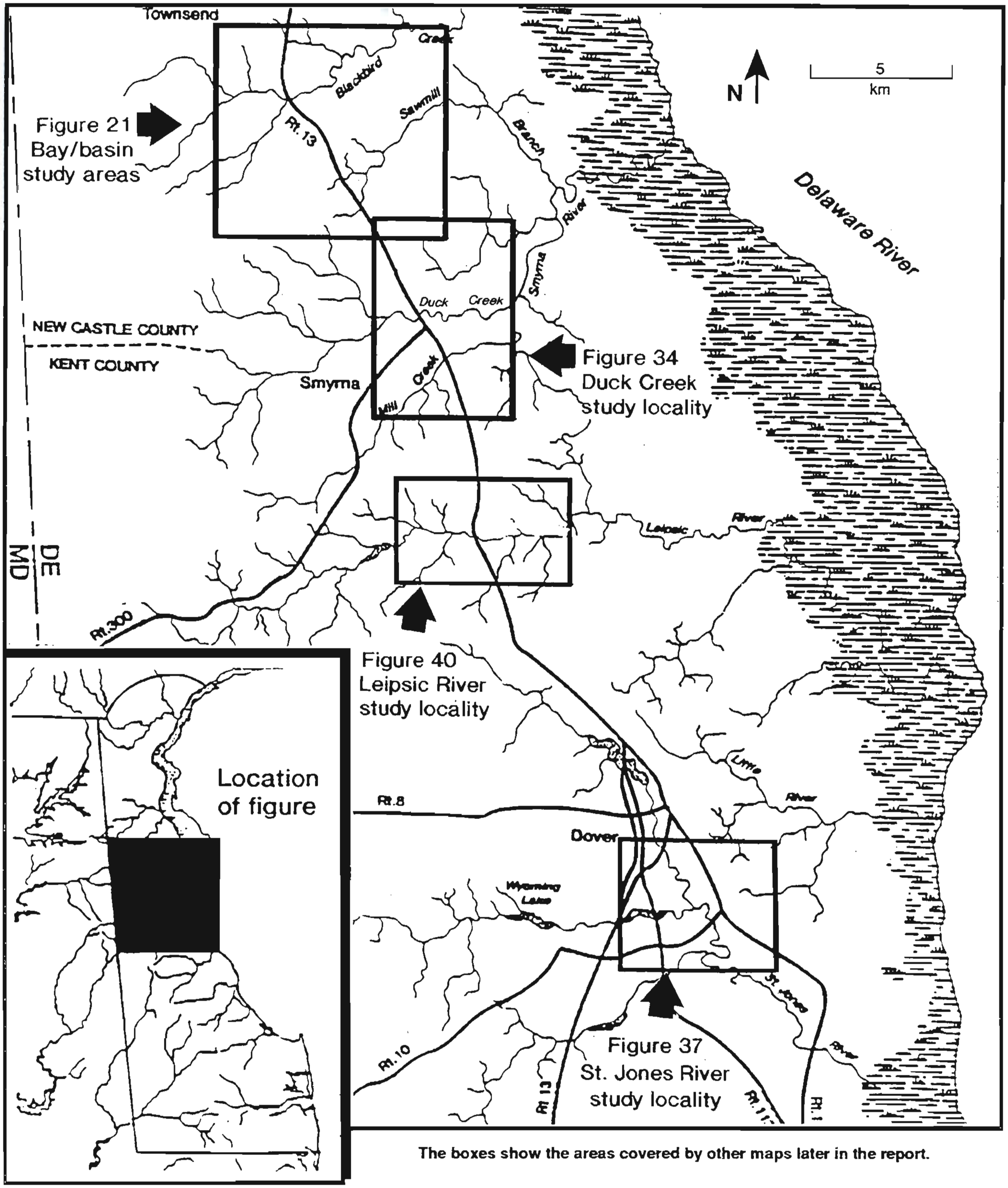
Based on the results of the preliminary planning and environmental impact studies, the Delaware Department of Transportation (DelDOT) selected specific highway alignments from within the larger study area (Figure 2). The next phase of archaeological research was the investigation of the specific alignments before highway construction began. Field survey was designed to identify archaeological sites within the proposed highway alignments and assess the potential significance of the sites (Custer, Bachman, and Grettler 1987). The details of the surveys are reported by Bachman, Grettler, and Custer (1988) and Hodny, Bachman, and Custer (1989).

After surveys identify archaeological sites that may be significant, further test excavations are carried out (for example, Grettler et al. 1991). Testing entails controlled excavations to determine if the sites are well preserved, contain especially important information, or are associated with a particular historic person. If there is no way to avoid destroying significant archaeological sites during highway construction, then full scale excavations are undertaken to record the important information about the past contained in the ground. The environmental studies by Rogers and Pizzuto, and by Brush, (this volume) were carried out in conjunction with excavations at significant prehistoric archaeological sites in the path of highway construction. Excavations at these sites (Figure 3) were completed during the summers of 1990 and 1991. Site excavation reports are in preparation.

As documented in the reconnaissance, planning, and survey reports for the State Route 1 archaeological study (Custer et al. 1984; Custer and Bachman 1986a; Custer, Bachman, and Grettler

FIGURE 2

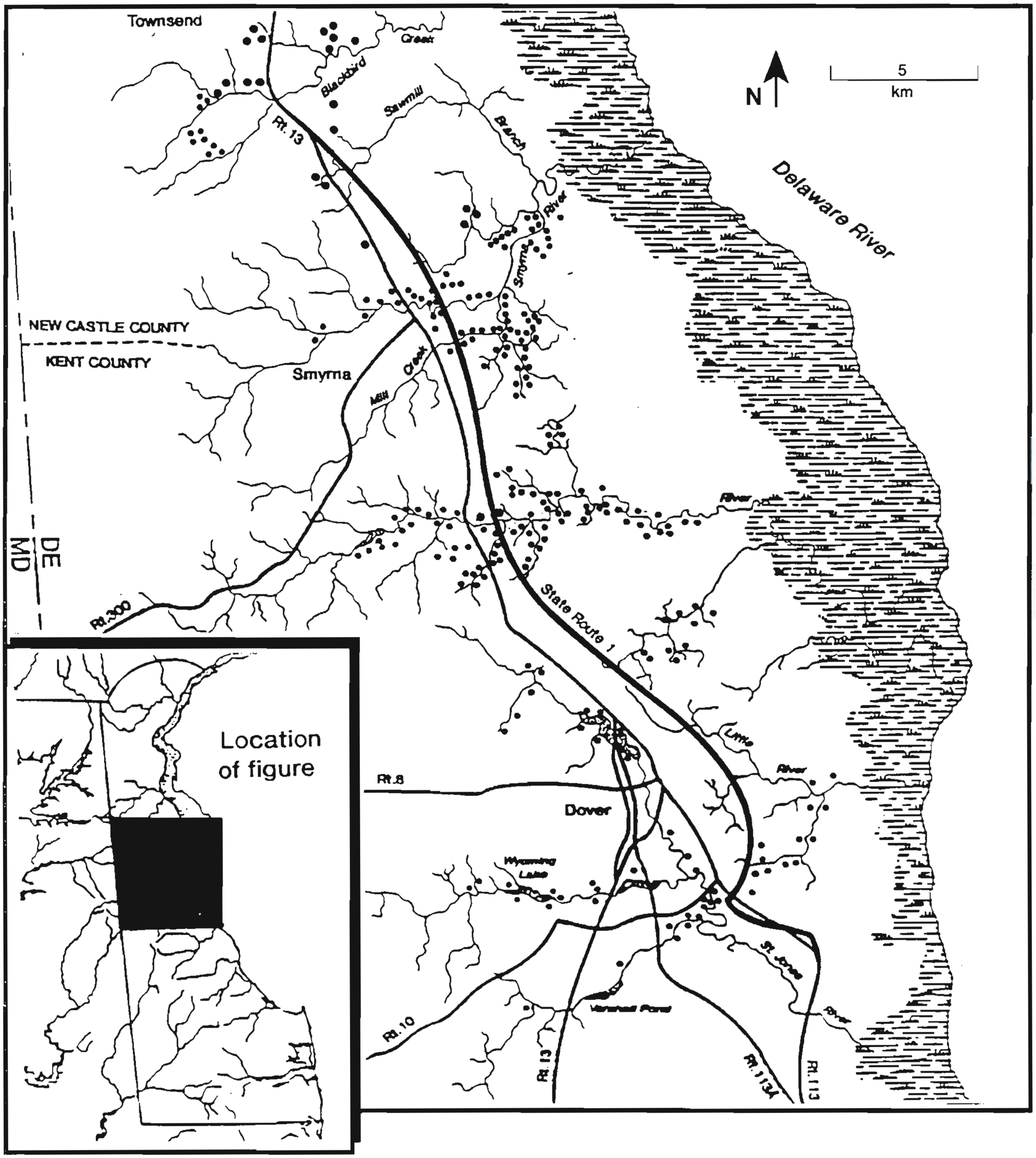
State Route 1 Corridor and Paleoenvironmental Study Localities



The boxes show the areas covered by other maps later in the report.

FIGURE 3

Prehistoric Archaeological Sites Along the State Route 1 Corridor



1986), prehistoric people were closely tied to the physical environment because they lived off the land - hunting, fishing and shell fishing, and gathering wild plant foods, such as nuts, wild rice and other seeds, berries, and edible roots and shoots (Custer 1984a). At some sites the remnants of meals are preserved in storage pits, fire places, or trash dumps, but often clues to past life styles are inferred by knowing the environment of the past at the time of occupation.

Another reason why archaeologists collaborate with specialists from other fields of research in reconstructing past environments is to understand the landscape changes that have occurred since prehistoric occupation of a site or region. Geological processes can bury or erode sediments, or shift artifacts and other remains from their original location of use or discard. In other words, archaeologists must understand how a site was formed in order to understand what the finds mean about people living in the past. Reconstructing past environments places archaeological finds within a context that is relevant to the people who lived there.

One more reason for undertaking the studies described in this report, rather than relying on studies carried out for other purposes, is that local environments are often obscured by large scale regional studies. It may be an error to extrapolate environmental studies at one locality to another; therefore, local, specific studies aimed at archaeological questions must be carried out. Furthermore, some earlier research into the environments of the Delmarva Peninsula, as discussed in a later section, have suggested that the regional data covering the Middle Atlantic coastal plain in general do not apply to some situations in Delaware (Custer 1984b; Custer and Watson 1987:87).

PALEOENVIRONMENTAL METHOD AND THEORY

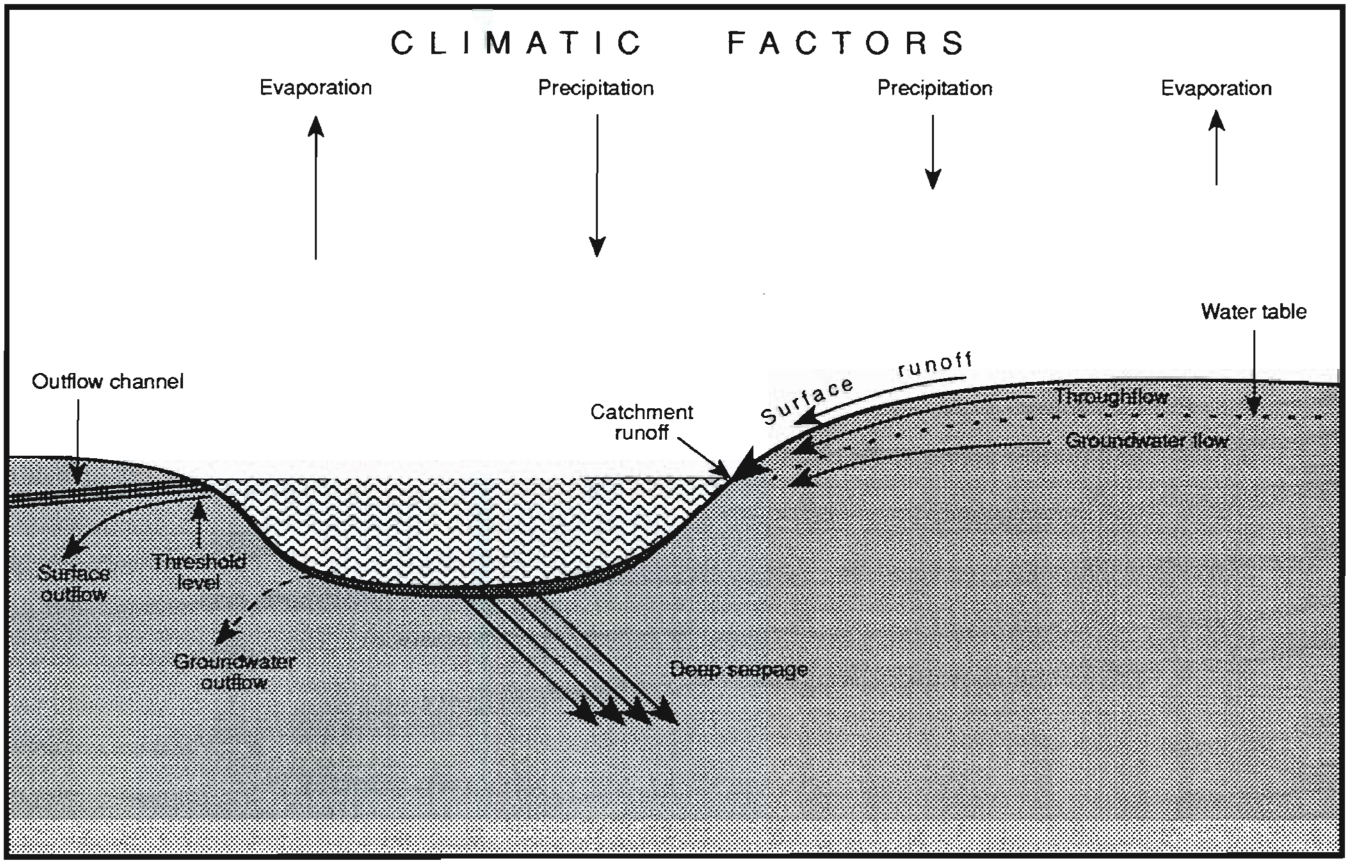
A variety of techniques have been developed by geologists and ecologists for studying past environments. Geologists combine studies of sedimentary environments - places where gravels, sands, silts, or clays have been deposited - with landscape studies to determine the processes that acted in the past. Ecologists use studies of plant fossils to place trees and other plants onto the landscape. Archaeologists add people into these recreated landscapes. The following section provides a background introduction to some of the assumptions and methods used in the technical studies presented later in this volume.

Sedimentary Analysis

Sediments are layers of mineral and organic particles laid down through the actions of water, wind, and other natural processes. Environmental reconstructions rely on the analysis and interpretation of sedimentary deposits. Where sediments accumulate over time, such as in lakes, marshes, floodplains, or at the base of slopes, a record of the environmental conditions is preserved (Reineck and Singh 1980:3-7). Environments are recreated by comparing the physical, chemical, and biological properties of sediment samples from ancient environments to modern samples from known environments (Reineck and Singh 1980:179-502). Water is the primary mover of sediments in temperate environments; however, winds also move sediments and there is evidence for this on the Delmarva Peninsula (Curry and Custer 1982; Foss et al. 1978; Ward and Bachman 1987).

Gaps in sedimentation can result from either a lack of deposition during an interval of time, or from erosion of sediments deposited earlier. Gaps in sedimentation yield environmental information because

FIGURE 4
Factors Affecting Water Levels in Lakes



Precipitation in the form of rain and snow falls directly into the lake and runs off from the ground surrounding the lake. Other run-off enters the lake through streams flowing into the lake, or as ground water. Water is lost from the lake through outlet streams, ground water flow, seepage into bedrock, and evaporation. Lake levels are ultimately controlled by the ratio of precipitation and evaporation. (After Dearing and Foster 1986)

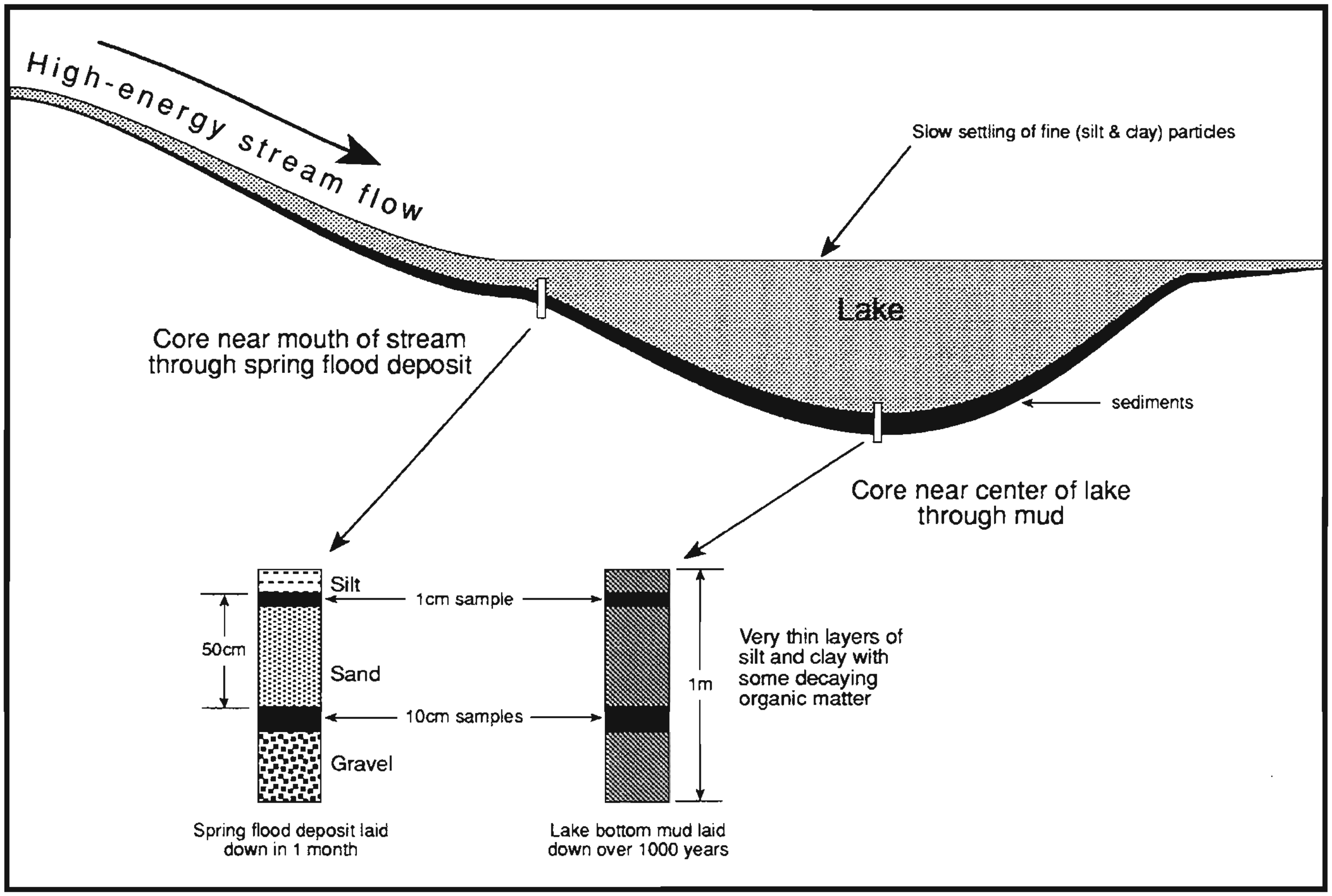
periods of time without accumulation suggest different environmental conditions than periods of deposition. For example, a pond dries up either because its water source has been diverted or the climate has become drier (Figure 4). Studies of fossil pollen, discussed later, are usually carried out on lake muds because lakes receive a relatively constant and continuous supply of organic sediments, such as decaying plant matter, or mineral sediments, such as sand and silt, washed in off the slopes of the surrounding landscape or carried in by streams.

The rate at which sediments are deposited affects the time resolution of environmental reconstructions. Rapid deposition, such as sand and mud deposited by spring flooding, can yield detailed records of vegetation because less time is represented by each sample of sediment and closely-spaced samples are separated by shorter time intervals. Where deposition is slow, like at the bottom of a lake, each sample includes a longer period of time and closely-spaced samples are further apart in time (Figure 5).

In rivers and lakes different types of sediments are deposited depending on the speed of waters movements, so a sediment deposit can record changes in water flow. However, erosional episodes are common in river deposits because river channels are active and move as precipitation and run-off vary and material is eroded and deposited within the stream channel.

FIGURE 5

Sediment Sampling and Sediment Accumulation Rates



The same size sample from sediments laid down under different conditions will represent different amounts of time. The spacing of samples within a core also affects the time resolution of the sampling.

Another factor influencing streams on the Delaware coastal plain is sea level (Kraft 1971). Since the end of the last ice age about 14,000 years ago sea level along the Atlantic coast has generally risen (Belknap and Kraft 1977; Fletcher 1988). As sea level has risen the lower reaches of streams and rivers have been progressively drowned by marine waters. Tides that influence the mouths and lower channels of streams can carry mud upstream and also introduce other chemical and biological actions that influence sediment deposition. For example, marine organisms that feed by filtering water excrete pellets of mud that can act like grains of sand until they break apart later. Also when fresh and salt water mix together in estuaries silts and clays stick together and act like larger particles (Kraft 1971; Reineck and Singh 1980:315-320). Thus, recreating environments based on river deposits is more difficult than for lake deposits. When geologists select a location for sediment study, they try to find a place where only one process at a time has been acting.

Geological Cross Sections. Paleoenvironmental studies are best conducted by constructing profiles, or transects, across the landscape. Cross-sections show the horizontal and vertical variability in deposits at a locality (for example, see Figures 30, 49, or 57). Transects of cores can be connected to create a three dimensional representation of sediment accumulations. Thus, the process of sedimentary analysis for recreating prehistoric environments involves a sequence of steps:

1) describe and characterize the sediments in a core, excavation, or natural exposure;

2) analyze and relate the sediments to modern analogs that identify the environment in which the sample was deposited;

3) determine the dates of deposition;

4) correlate the sequences of sediments from different locations to create cross-sections;

5) relate the local sequence to regional sequences and events.

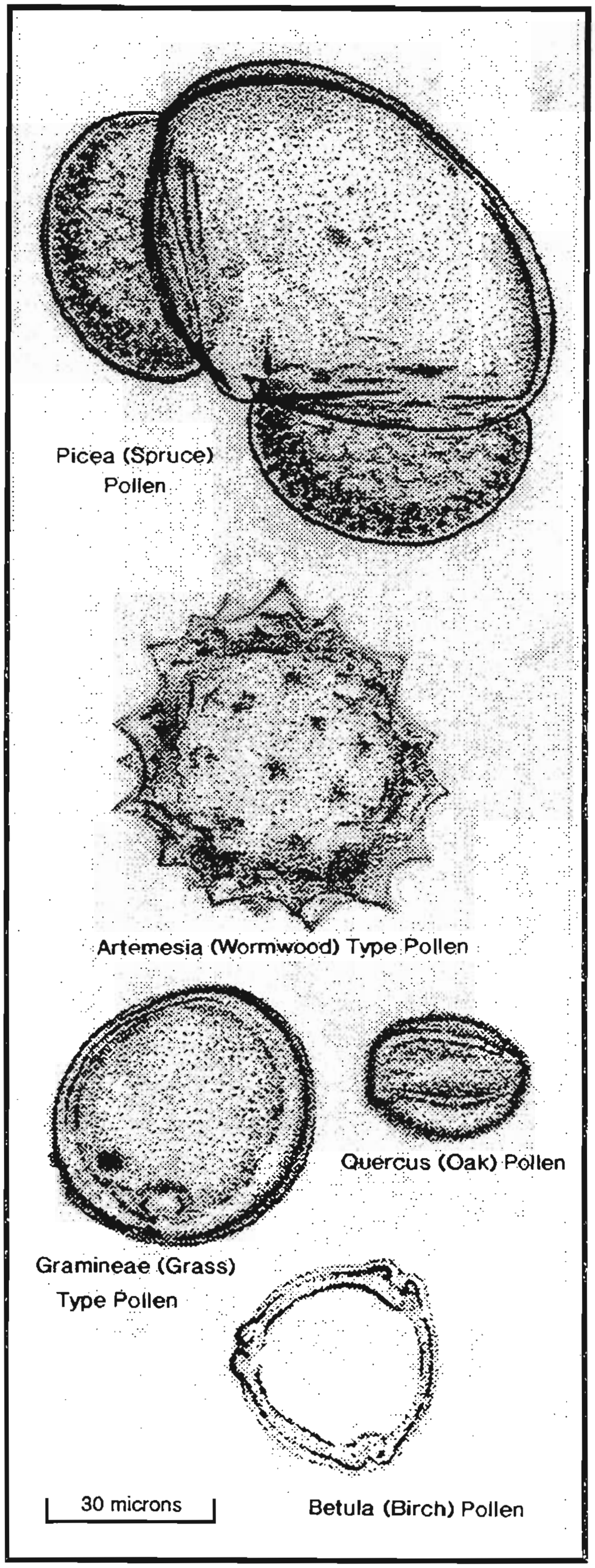
Step two above might include the study of fossils, both visible and microscopic, within the sediments. Many types of organic remains are found preserved in sediments, including seeds, pollen, plant fragments, diatoms and plankton, insect remains, fungal spores, and sometimes fish and other bones. Chemical or magnetic studies can also yield useful information depending on the goals of the research and the sediment characteristics of the study site. Knowledge of modern environments provides the means for determining the environments represented by ancient sediments.

Pollen Analysis

Pollen analysis is one of the most powerful tools for reconstructing prehistoric environments. All flowering plants produce pollen during their reproductive cycle. Pollen is the male gamete that combines with the female ovum to produce seeds (Birks and Birks 1980:177-179; Faegri and Iversen 1975:18). Pollen is microscopic ranging in size from about 5 microns to about 200 microns (1 thousandth to 5 hundredths of an inch). Pollen of different plants can have distinctive shapes and surface features (Figure 6). However, some plant groups produce pollen that cannot be easily separated. For example, pollen of spruce, fir, and pine can be distinguished from one another, but pollen of black, white, and red spruce are too similar to tell apart.

FIGURE 6

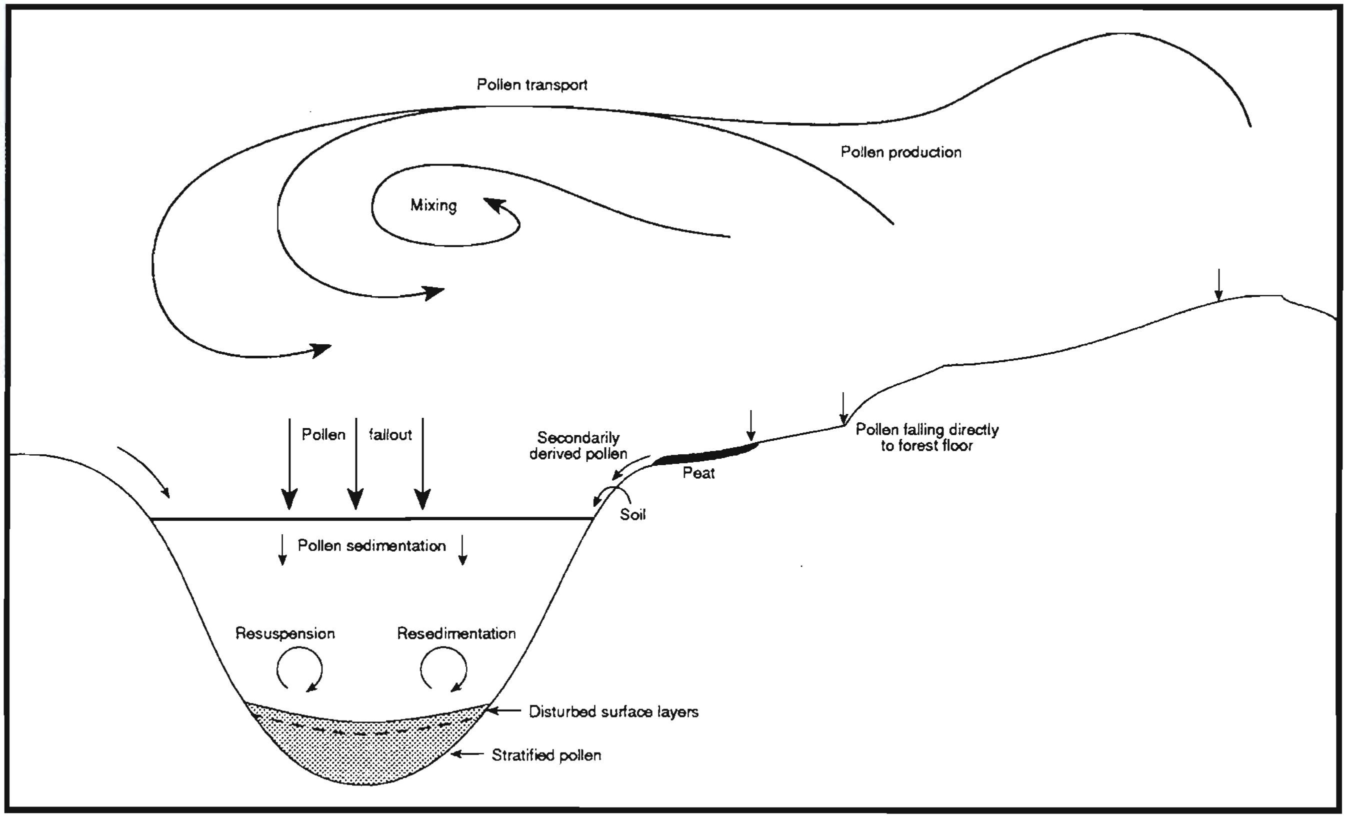
Typical Pollen Grains



(Based on photomicrographs in Moore and Webb 1978) The variations in form and structure of the pollen shell allow identification of different plants and trees.

FIGURE 7

Production and Dispersal of Pollen Grains



Most pollen grains that are deposited in lake sediments are from plants that are wind pollinated. Pollen falls onto the lake surface or is carried in by rain. After pollen is incorporated into the sediments on the lake bottom, water movements--due to waves or currents--can disturb the stratigraphy. (After Delcourt and Delcourt 1987a; and Moore and Webb 1978).

The pollen of many kinds of plants is spread by wind; while other plants rely on insects for pollination. Most plants with colorful, fragrant, and showy flowers are insect pollinated and their pollen is sticky. Most woody plants, including trees and shrubs, are wind pollinated and produce large quantities of pollen in the spring (as those of us with hay fever are well aware). Pollen dispersal by wind is a complex process (Birks and Birks 1980:179-183; Jacobson and Bradshaw 1981; Prentice 1986). Some falls directly to the ground; some is carried by winds below the leaf canopy of the forest; and some is carried aloft above the trees (Figure 7). The type of vegetation on the landscape can influence how pollen is carried by the wind. For example, winds close to the ground in a dense forest are not as strong as those on an open prairie. The shapes and sizes of pollen grains affect how far they can be carried by winds. For example, corn pollen is round and heavy and usually falls very close to the corn plants; however, pine pollen has light-weight bladders that keep it up in the atmosphere where it can be widely dispersed by winds. One final factor that has to be considered in pollen analysis is that different kinds of plants produce different amounts of pollen.

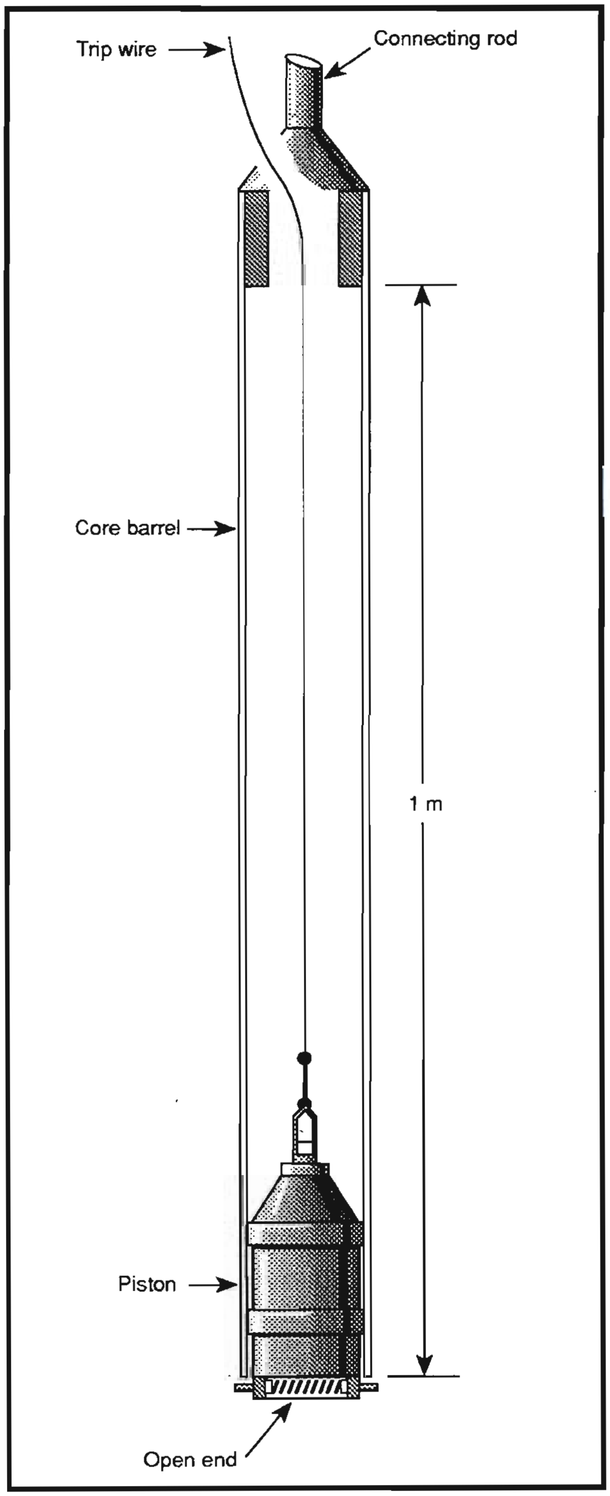
Pollen in the air eventually falls to the ground. Of course, some pollen finds its way to the female flowers of the same type of plant to produce a new generation of seeds. Excess pollen either deteriorates and is destroyed, or is preserved in favorable environments. Pollen grains are composed of a complex organic compound that is one of the most resistant substances known (Birks and Birks 1981:187-188; Fagrei and Iversen 1975:23). Sporopollenin, the substance that forms the outer shell of the pollen grain, is virtually a natural plastic. However, extended exposure to air (oxidation) will destroy pollen. Rapid burial, or deposition in a wet environment, can preserve pollen. Therefore, to use fossil pollen to study past environments, it is necessary to find locations, such as lakes or bogs, where pollen has accumulated with mineral and organic sediments over time.

Pollen can be preserved in soils; however, mechanical, chemical, and biological action can degrade or destroy pollen so that a biased picture of vegetation can result (Dimbleby 1985:1-26; Havinga 1971; King 1975). In addition, pollen deposited at different times in the past can be mixed in the soil profile (Dimbleby 1985:1-20). Pollen data from soils are thus difficult to interpret. Nonetheless, pollen from soils can provide some useful information in certain cases (Dimbleby 1985). Pollen has been found in the soil filling prehistoric fire, house, and storage pits in Delaware (Thomas 1981).

The basic assumption of pollen analysis is that the types of pollen deposited at a particular place are representative of the range of plants growing in the area at the time (Birks and Birks 1980:156-157; Fagrei and Iversen 1975:123-127). The great quantity of pollen and its mixing in the atmosphere before deposition are assumed to yield a pollen assemblage that is characteristic of the type of forest or other vegetation (for example, prairie, wetland, tundra) that produced the pollen. Therefore, changes in pollen through time represent changes in vegetation through time, which in turn reflect climate changes, as well as other factors that affect the vegetation of a region.

Although some pollen is transported great distances in the upper atmosphere and deposited far from its source, most pollen is deposited close to its source. The type of location chosen for study will affect the ways in which the fossil pollen represents the vegetation around the site (Jacobson and Bradshaw 1981; Pennington 1979). In any pollen sequence there will be regional pollen from the plants growing for miles around the site as well as local pollen from plants growing at the site. A small

FIGURE 8
Livingstone Piston Corer



The corer is a metal tube fitted with a piston. The corer is lowered to the lake bottom from a boat or other platform on the lake surface. The trip wire holds the piston in place while the core barrel is forced into the lake mud by downward pressure on the connecting rod. The piston forms a vacuum in the core barrel so that the lake mud can be brought to the surface. The lake mud can then be pushed back out of the core barrel and packed for transport to the laboratory.

site, such as a pond one acre in area, will reflect the vegetation of a small region because the proportion of pollen from plants close by will be greater than the proportion of pollen from plants far away. On the other hand, a large lake of several hundred acres size, for example, gathers pollen from a larger region and the amount of pollen from plants close to the lake will be small compared to the amount from plants further from the lake (Jacobson and Bradshaw 1981). Also a very small site, such as a small bog hollow under a canopy of trees, will emphasize the local pollen over the regional input because pollen from far away will be carried past the site by winds above the treetops.

Since wet environments are best for pollen preservation, lake muds or marsh peats are sought for study. Hollow metal or plastic tubes (Figure 8) pushed into the lake bottom or marsh and then pulled back out recover a core from the sediment deposit. Pollen is extracted from the core by taking small volumes of mud at intervals along the core. An exotic pollen type (Eucolyptus pollen is often used in North America), or a slurry of microscopic plastic spheres, is added to the sample of mud in known quantities. The sample is then screened to remove large debris and treated with a variety of strong acids and other chemicals to leave only the pollen grains (Faegri and Iversen 1975; Pearsall 1989). A sample of only one cubic centimeter can contain hundreds of thousands of pollen grains. Pollen grain types are counted while scanning microscope slides and examining individual pollen grains at 400 times magnification, or greater. Three hundred or more pollen grains must be counted to get a statistically significant sample of the major pollen types (Birks and Birks 1980).

Changes in pollen through time can be compared through three different measures calculated from the pollen counts on each sample. First, the percentage of each pollen type relative to other pollen types can be plotted by time, or depth in the core, on a series of graphs to form a pollen diagram (see Newby, Webb, and Webb in this volume). On this type of pollen diagram, for example, if the percentage of oak pollen increases from one sample to the next, then the percentages of other types of pollen must decrease. The second measure can be calculated if the exotic pollen or marker grains (plastic spheres) are counted along with the pollen in each sample. The numbers of pollen grains per unit of volume in each sample of sediment (pollen concentration) can then be calculated. The pollen concentration is an absolute measure because the concentration of one pollen type is not affected by the concentration of other types. Finally, if absolute dates can be assigned to the core samples through radiocarbon dating, or other absolute dating techniques, then the pollen accumulation rate (number of pollen grains per square centimeter per year) can be calculated. Brush (this volume) bases her interpretations of prehistoric environments on the pollen accumulation rate (sometimes referred to as the pollen influx) of cores through marshes.

The pollen study in this volume by Newby, Webb and Webb focuses on very small ponds. Thus the emphasis is on the vegetation near to the ponds, rather than on vegetation at distances away from the ponds. The study by Brush, reported in this volume, was carried out on cores from the margins of free-flowing streams; therefore, some of the pollen could have been transported by the stream, as well as by winds. It is often difficult to interpret pollen from river and stream deposits because there may be gaps in the sequences and some pollen may be eroded and redeposited from earlier deposits upstream. Nonetheless, the local vegetation is emphasized by Brush's use of the pollen accumulation rate, rather than pollen percentages.

The local character of the environmental information provided by the studies presented in this report is what makes them useful and important to archaeologists studying the prehistoric human habitations (archaeological sites) nearby. Knowledge of the local environment can help explain why people chose to live at a particular place and what types of environments they exploited.

TABLE 1

Geologic Time Scale*

Years Before Present	Epoch		Period
0			
	Holocene		
10,000			Quaternary
	Pleistocene		
1,600,000			
	Pliocene	Neogene	
5,300,000			
	Miocene		
23,700,000			Tertiary
	Oligocene	Paleogene	
36,600,000			
	Eocene		
57,800,000			
	Paleocene		
66,400,000			

* Based on DNAG 1983 Time Scale, Geological Society of America.

Plant Macrofossils

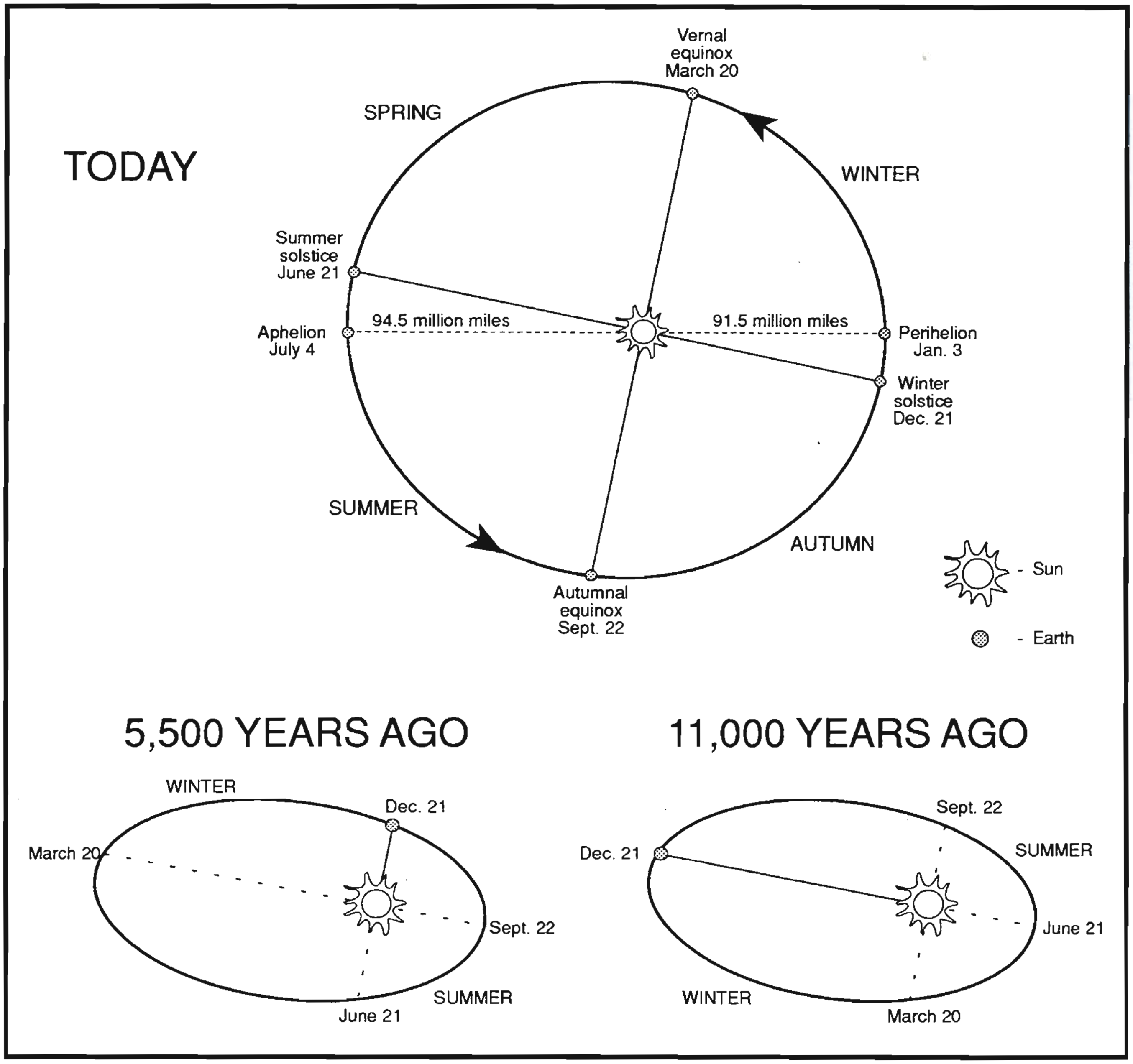
Plant fragments (often referred to as macrofossils to distinguish them from microscopic plant fossils, such as pollen) are pieces of, segments of, or whole individual plants, including leaves, stems, bark fragments, twigs, seeds and so forth (Mannion 1986). Large plant fragments are not transported far by wind and water in comparison to pollen grains. Pollen grains do not provide direct evidence of plants growing at a particular location because pollen is transported to the place where it is preserved - sometimes for great distances. Plant macrofossils, on the other hand, unequivocally show the presence of particular plants growing around a lake basin or within the drainage basin of a stream.

Another advantage of studying plant macrofossils is that large fragments of plants can often be identified to the species level (for example, white oak), while most pollen can only be narrowed to the genus level (for example, oak of some type). Plant macrofossils require a suitable environment for preservation, and as with pollen, rapid deposition and a wet environment increase the chances of preservation. However, the shear volume of pollen produced by plants and the durable pollen shell make pollen grains a much more common indicator of past vegetation. Brush's study of past environments, in this volume, combines the evidence of fossil pollen with plant macrofossils from the same cores. The plant macrofossil information can be used to help interpret the pollen data.

REGIONAL PALEOENVIRONMENTAL AND CLIMATE CHANGE

Geologists refer to the past 2 million years as the Quaternary period (Table 1). The hallmark of the Quaternary is the onset of cold conditions that caused the extinction of many marine plankton (Berggren

FIGURE 9
Variations in the Earth's Orbit

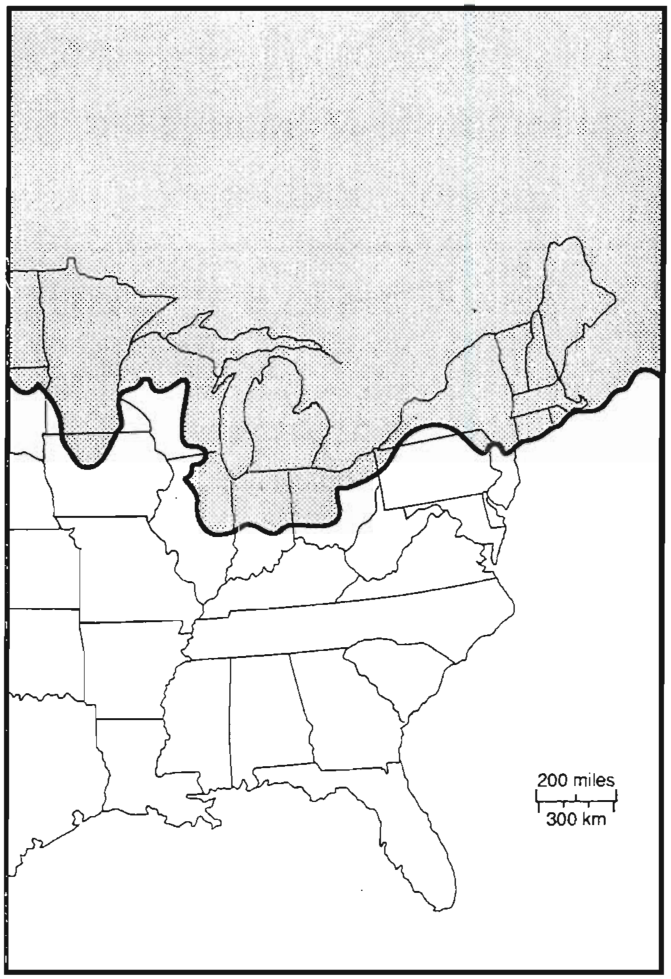


The Earth slowly wobbles on its axis as it moves around the sun. The wobble causes the relationship between the seasons of the year and the distance from the Earth to the sun to change through time. The result is that the amount of sunlight reaching the surface of the Earth changes over time (From Imbrie and Imbrie 1979).

1980). The Quaternary is divided into two parts: the Holocene is the last 10,000 years, while the Pleistocene comprises the remainder of the Quaternary. The Pleistocene is the time of the ice ages (Flint 1971). Contrary to popular perception there have been many more than four continental glaciations. During the Pleistocene, there were approximately 20 "ice ages" occurring in cycles averaging 100,000 years (Imbrie and Imbrie 1979; Ruddiman and Wright 1987). The major causes for the build up of ice on the continents are cycles of change in the earth's orbit around the sun and a wobble in the earth's spin (Figure 9; Imbrie and Imbrie 1979). North American archaeologists are concerned with only the most recent glacial age because there is no good evidence of people in the New World until the end of the last glaciation (Dincauze 1984; Jelinek 1992; Lynch 1990; West 1983).

FIGURE 10

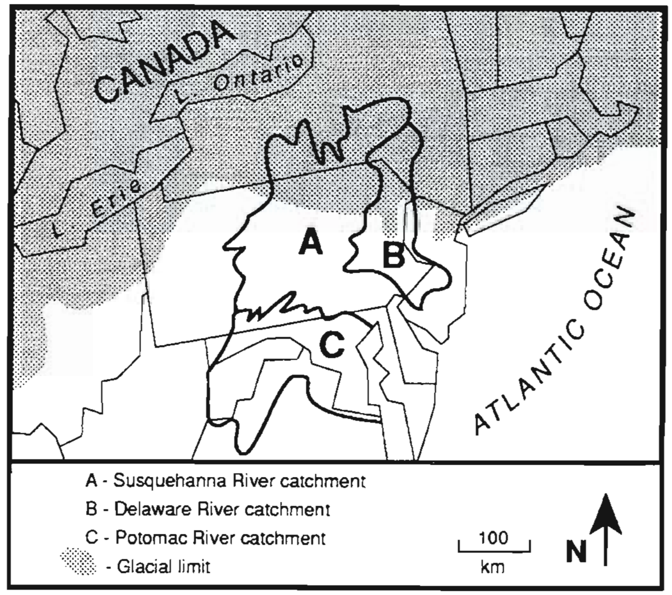
The Extent of Ice During the Last Glacial Maximum and Vegetation Zones



The maximum extent of the ice sheet between 21,000 and 14,000 B.P. (from Denton and Hughes 1981). Vegetation zones were pushed south by the colder climate, and sea level was lower due to the water locked into ice on land.

FIGURE 11

Delaware and Susquehanna River Drainages



The relationship between the maximum extent of glacial ice and the drainages of the Delaware, Susquehanna, and Potomac Rivers. The Delaware and Susquehanna Rivers carried melt water away from the ice sheet margins when melting began about 14,000 B.P.

The Last Glacial Maximum and Deglaciation

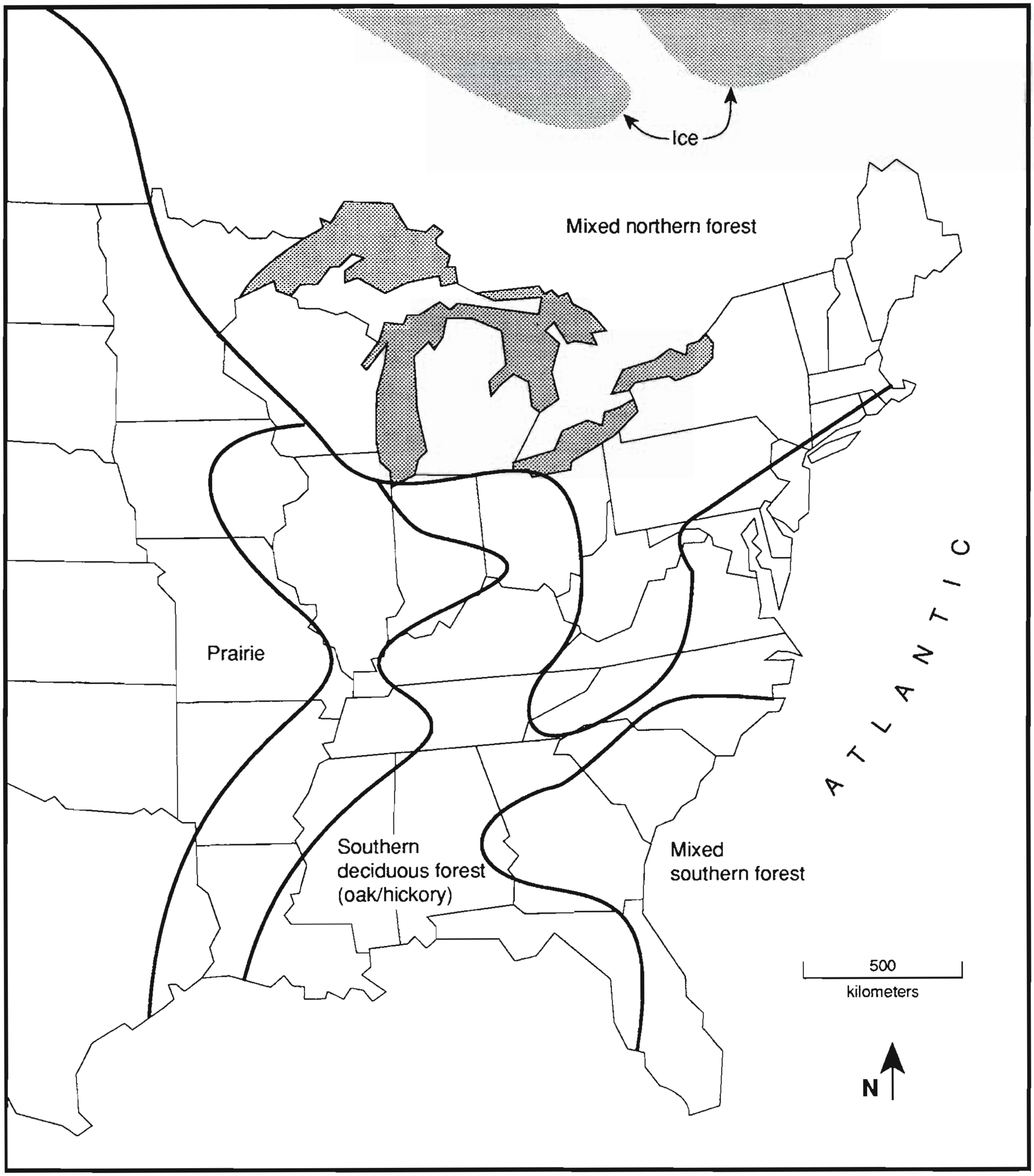
Glaciers are ice that is thick enough to flow at the bottom under the pressure of its own weight. At the maximum extent of the last glaciation, from about 21,000 to 14,000 years before present (BP), a dome of ice more than a mile thick centered over Hudson Bay and extended across all of eastern Canada and New England and reached as far south as northern Pennsylvania (Mayewski, Denton, and Hughes 1981). The ice margin stretched across the Dakotas and merged with ice covering the Rocky Mountains (Figure 10).

Climate zones were pushed south during the glacial maximum so that arctic tundra stretched up to 60 miles south of the ice (Clark and Ciolkosz 1988; Watts 1983) (Figure 10). Spruce and northern pine trees grew in Georgia (Watts 1980; Whitehead 1973) and Louisiana (Delcourt et al. 1980). Sea level was lowered over 300 feet so that the continental shelves were almost completely exposed because the ice sheets kept water on land instead of in the oceans (Bloom 1985).

The ice sheets began to melt and break up starting about 14,000 BP. Melting was very rapid as sea level rise brought marine waters into contact with the ice (Denton and Hughes 1981). Large volumes of cold water raged down rivers, including the Susquehanna and Delaware Rivers (Baker 1983:116), draining

FIGURE 12

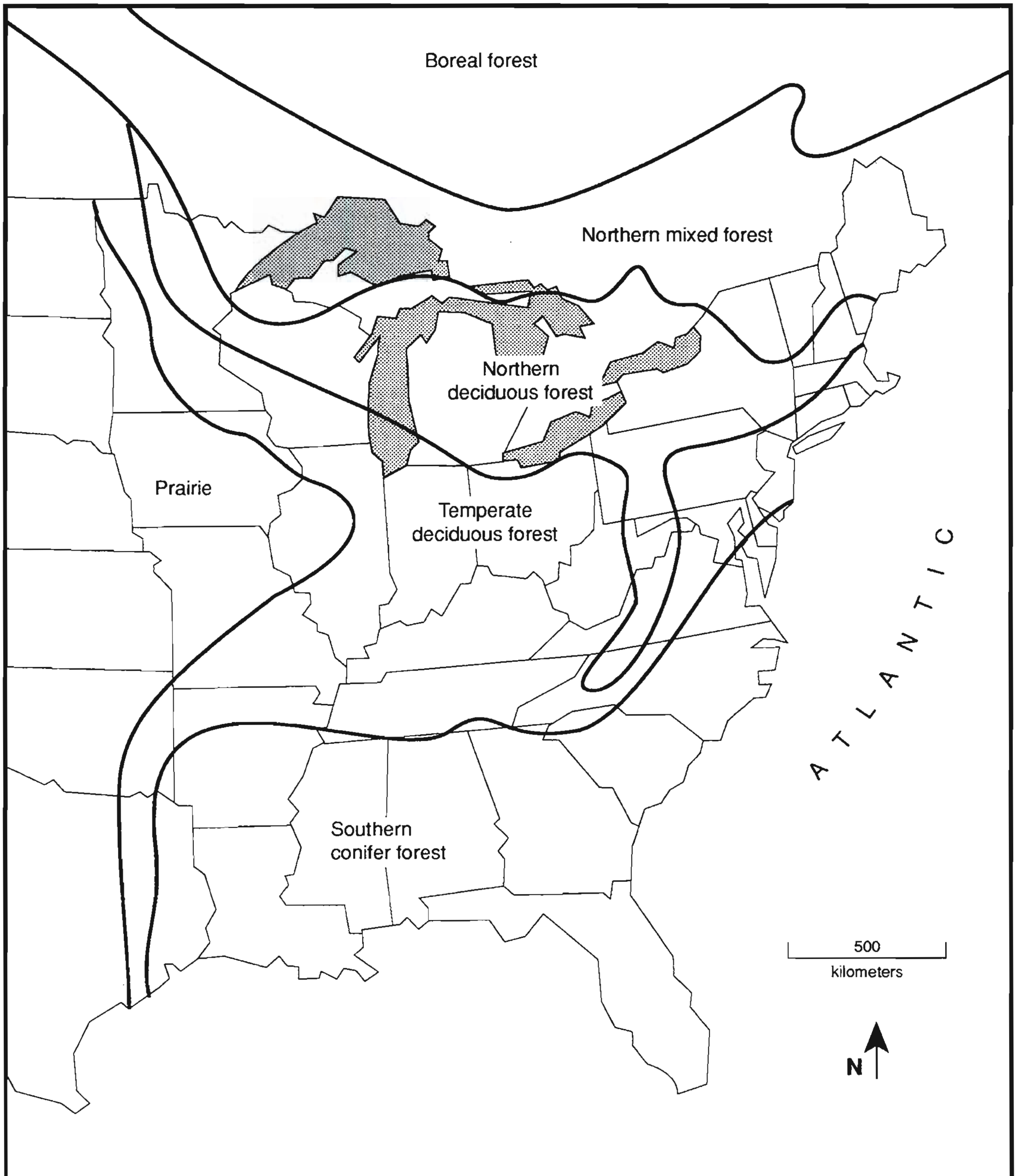
Vegetation Zones 7,000 Years Ago



(Based on Denton and Hughes 1981; and Jacobson, Webb, and Grimm 1987). The climate of the eastern United States was substantially warmer and drier 7,000 years ago than it is today. One result of the warmer climate was the eastward expansion of the prairies that now cover the Great Plains.

FIGURE 13

Present Vegetation Zones



(Based on Delcourt and Delcourt 1987a; and Jacobson, Webb, and Grimm 1987).

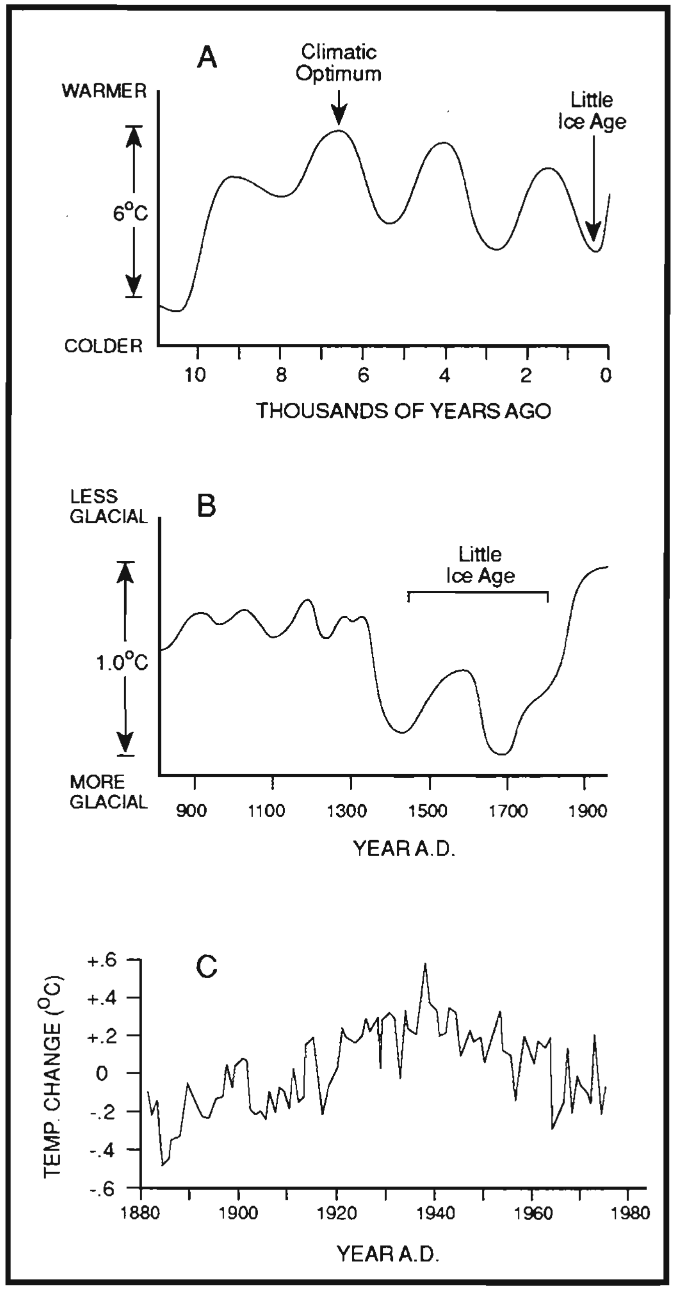
the ice sheets (Figure 11). However most melt water drained down the Mississippi and St. Lawrence Rivers from large lakes next to the retreating ice sheet (Teller 1990). The "Great Lakes" are remnants of these much larger lakes. The last glacial ice finally disappeared over northern Canada about 6000 BP (Mayewski, Denton, and Hughes 1981).

Plants species responded individually to the climate changes that melted the ice, but in general vegetation zones shifted northwards rapidly as the ice retreated (Delcourt and Delcourt 1987a,1987b; Gaudreau 1988; Webb, Bartlein, and Kutzbach 1987). Increased solar warmth in northern latitudes summers, reaching a maximum at 9000 BP (Kutzbach 1987:426), led to an eastward expansion of prairie vegetation (Figure 12), until about 7000 BP (Delcourt and Delcourt 1984). Solar radiation was 8% greater than at present in July, but winters were cooler; therefore, seasonal variation was greater at 9000 BP (Kutzbach 1987:426). At the same time boreal forest species (for example, spruce, fir, and northern pines) retreated far to the north of their present ranges (Jacobson, Webb, and Grimm 1987).

Since 9000 BP (11,000-7000 BP), conditions have gradually approached modern values and vegetation has shifted accordingly (Delcourt and Delcourt 1984; Gaudreau 1988; Watts 1983). Prairie shifted west and the boreal forest adopted its present configuration across Canada (Figure 13). Climate has been gradually cooling since about 9000 BP, but fluctuations have occurred (Figure 14; Denton, Hughes, and Karlen 1986) as in, for example, the "Little Ice Ages" (Grove 1988).

FIGURE 14

Climate Fluctuations Over the Last 10,000 Years



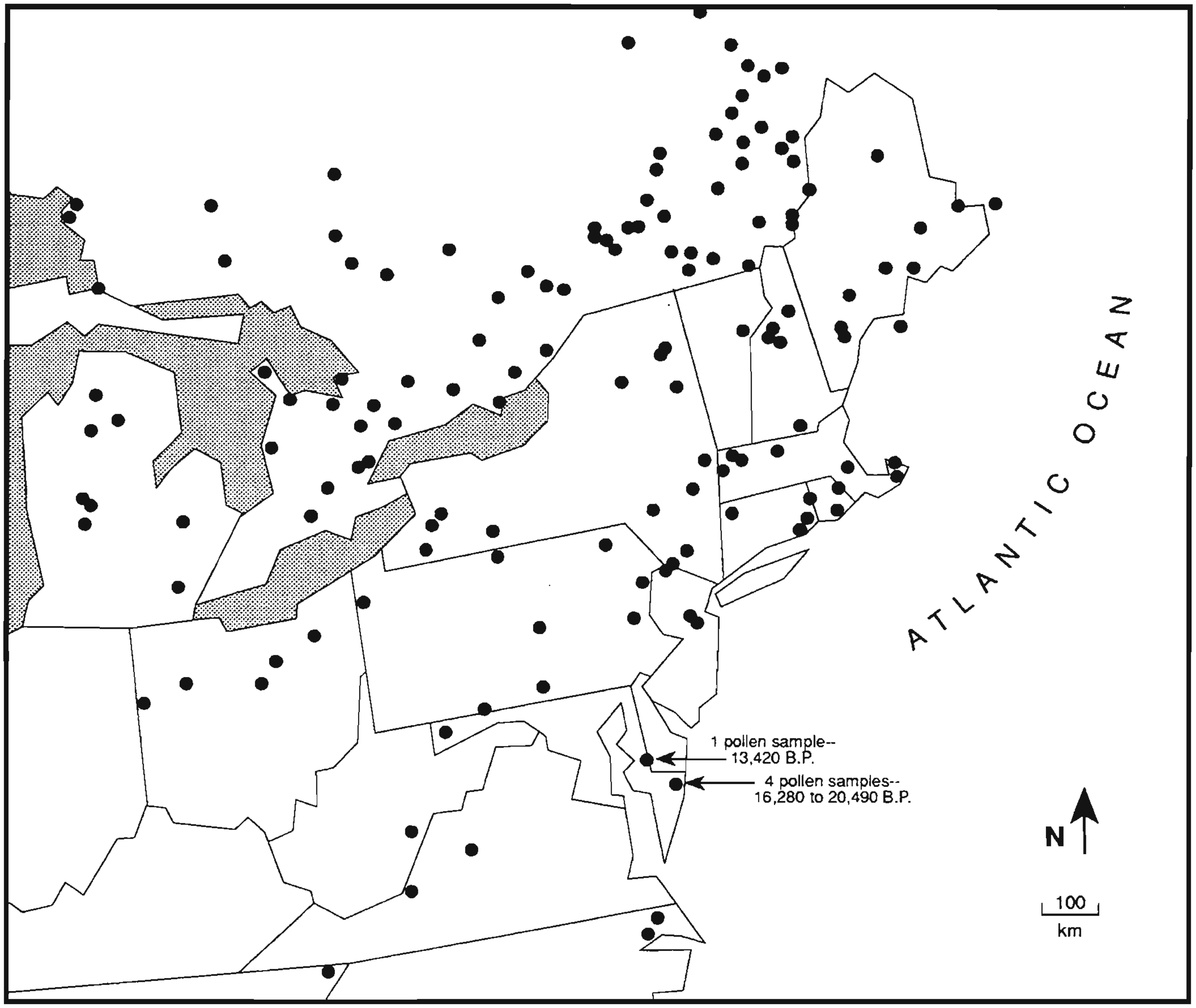
(From Imbrie and Imbrie 1979) A: Over the last 10,000 years; B: Over the last 1000 years; C: Over the last 100 years.

Holocene Environments

This section will concentrate on the Middle Atlantic region of the United States to provide the context for the State Route 1 environmental studies presented in this volume. The discussion is based on recently published

FIGURE 15

Eastern U.S. Pollen Study Localities



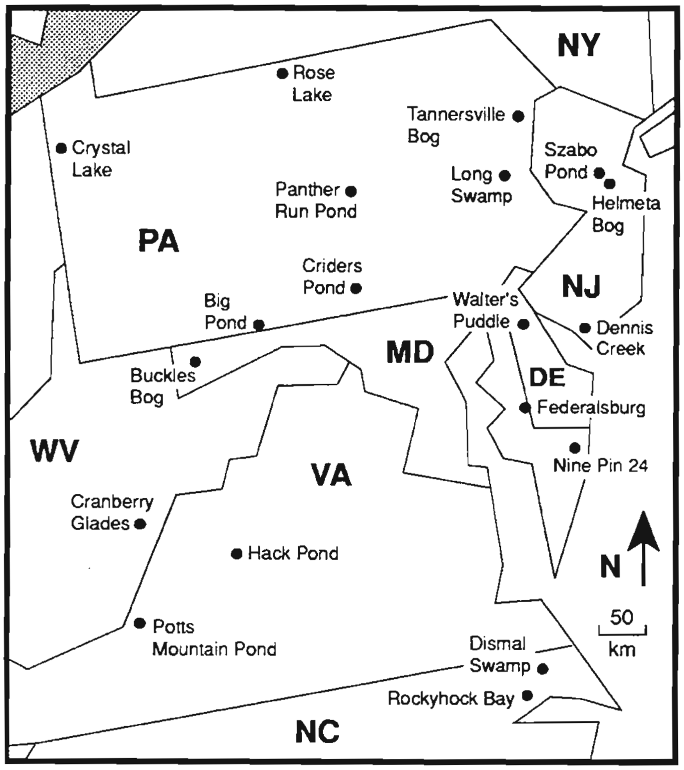
(From Gaudreau 1988) More studies have been undertaken within the area covered by ice during the last glaciation because more lakes and bogs are present.

reviews employing modern radiocarbon-dated studies of pollen and plant macrofossils. Individual ecological studies that relate to the Delmarva Peninsula are emphasized. Few ideal places for pollen studies exist south of the maximum glacial limit. Lakes that have held water throughout the last 10,000 years are rare. North of the glacial limit the scoured bedrock and irregular terrain of glacial deposits holds many lakes, and a generally cooler climate has maintained water levels. Thus, the density of pollen studies in New England and the northern Midwest is much greater than for the southern United States (Figure 15).

Complete Holocene pollen sequences nearest to the Delmarva Peninsula are from the Dismal Swamp (Whitehead 1972) in northeastern Virginia and Rockyhock Bay in northeastern North Carolina (Whitehead

FIGURE 16

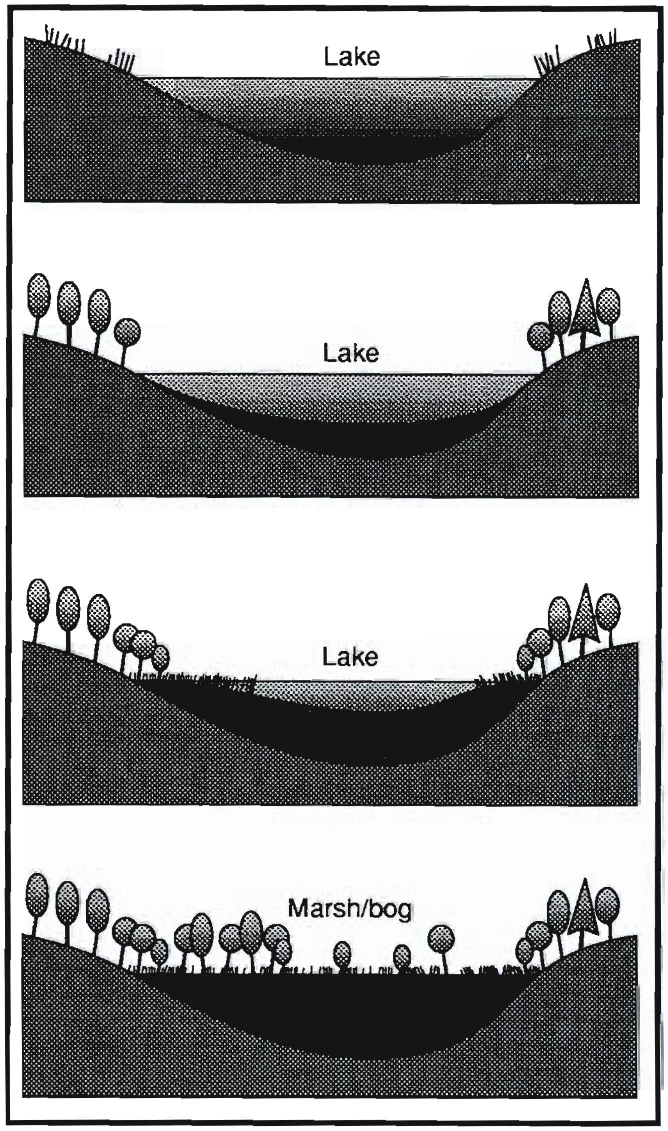
Pollen Study Localities in the Mid-Atlantic Region



(From Gaudreau 1988) Most of the studies have been on lakes or ponds in the Appalachian highlands. The studies in New Jersey and Delaware cover only short time intervals, so that there are gaps in our knowledge of past vegetation and climate.

FIGURE 17

Evolution of a Small Lake into a Bog or a Marsh

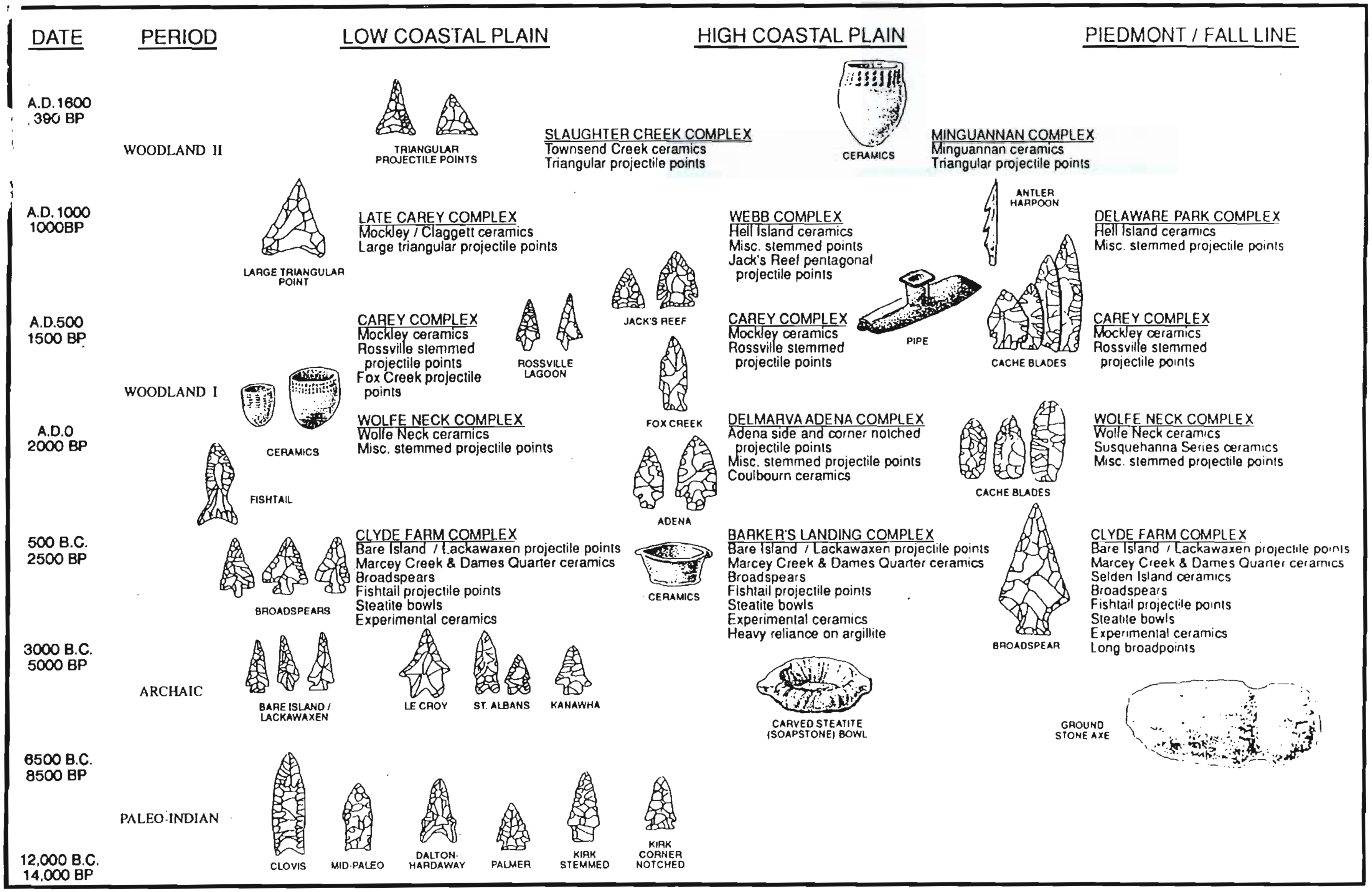


Lakes accumulate sediments carried in by streams and soil erosion, as well as decaying organic matter (leaves and other plant material) (from Whittaker 1975). Through time the lake fills in and a marsh or bog develops. Eventually the former lake may be completely overgrown.

1981), Tannersville Bog and Long Swamp in eastern Pennsylvania (Watts 1979), and Criders Pond in southern central Pennsylvania (Watts 1979) (see Figure 16). There are some difficulties in recreating the prehistoric vegetation of the region based on these studies. Most of the study localities started out as lakes but filled in with mud over time to become bogs (or even dried up for a time) (Figure 17). Some are now overgrown with trees. The pollen preserved in the sediments at the lakes and bogs, thus, represents different proportions of the area around the study site and the developmental history of the localities must be taken into account when interpreting and correlating the pollen and macrofossil information. In addition, most pollen sequences are not well dated. Radiocarbon dating is relatively expensive and usually only one or a few dates are obtained. These problems make it difficult to extend the vegetation and climate reconstruction at one locality to other areas. The discussion that follows is general; details that are important for the Delmarva Peninsula are lacking. The studies presented in this volume help to fill in those details.

TABLE 2

Cultural Complexes and Time Periods of Delaware



For the purposes of the discussion below the last 14,000 years is divided into three parts based on the most broad climate and vegetation trends. The divisions do not necessarily coincide with the divisions of time used by archaeologists in the region (Custer 1984a:30; Custer 1989:36), although some of the changes in prehistoric cultures were influenced by changes in the environment (Table 2).

Post-Glacial: 14,000 - 10,000 BP

Tundra conditions are evident at Long Swamp in eastern Pennsylvania 60 km (38 miles) south of the ice at the maximum of the last glaciation and also in northern New Jersey (Sirkin et al. 1970; Sirkin and Minard 1972). On the southern Delmarva peninsula there is evidence for stands of spruce trees scattered about on grassland and possibly tundra during the maximum of the last glaciation (Sirkin, Denny, and Rubin 1977). Spruce trees were one of the most abundant tree types in the mid-Atlantic forests at about 14,000 BP, and spruce trees were common until about 11,000 BP (Gaudreau 1988; Watts 1983). Regional climate was probably cold and wet, but air masses interacted with ocean currents and the retreating ice-margin creating atmospheric circulation patterns that were much different from the present patterns (Delcourt and Delcourt 1984; Kutzbach 1987).

Another factor to consider is the position of the coast. Between 12,000 and 10,000 BP sea level was much lower than at present, but was rising rapidly (Bloom 1985:220-222). The coast line of the Delmarva Peninsula would have been 100 km (60 miles) east of its present position (Bloom 1985:220-222; Edwards and Merill 1977).

Native Americans first inhabited Delaware sometime after 14,000 BP based on dates from Paleo-Indian period archaeological sites in the east (Custer 1989:81-86). Paleo-Indian peoples probably lived mainly by hunting animals that roamed the shifting woodland and grassland mosaic of vegetation on the landscape at the time. Game animals may have included musk ox, caribou, moose, and the extinct mastodon (Figure 18); however, modern game animals, such as white tailed deer, were also present in the region. Paleo-Indians probably led a wandering existence in small family groups (Custer 1989:95-98). Plant foods were not as important to the diet as later in time, perhaps because Paleo-Indians were relatively new to North America and had not yet learned which plants were useful, and the rapidly changing environments made plant foods hard to predict as they ripened throughout the year.

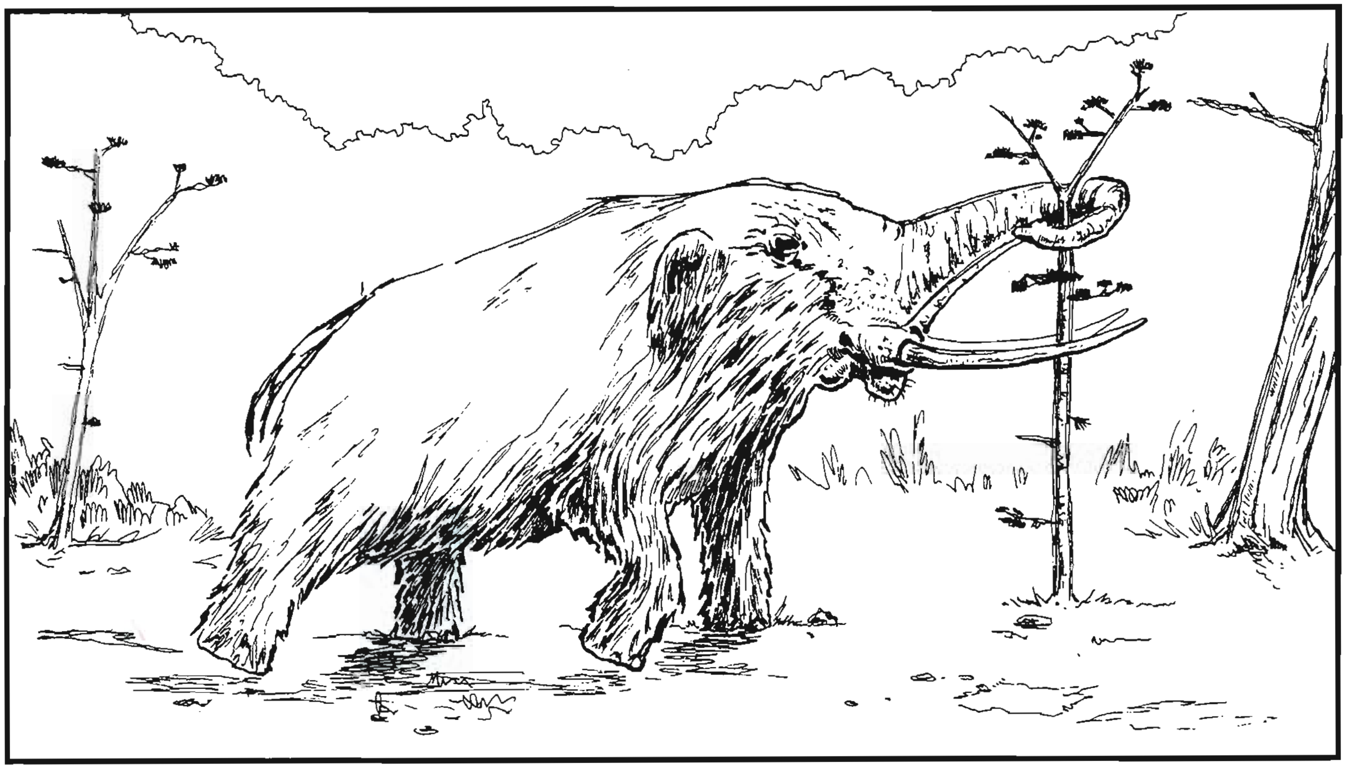
Paleo-Indian period archaeological sites have been found in northern Delaware and are concentrated near Iron Hill in western New Castle County (Figure 19) where there are outcrops of good stone for making tools (Custer 1989:102-109). Another concentration of Paleo-Indian sites occurs along the center of the Delmarva Peninsula where swamps based on poorly-drained soils are concentrated (Figure 19). It is likely that the mosaic of soil types in this area increased the diversity of plants and animals available for exploitation, and that fresh water sources, such as ponds, were more common on the poorly-drained soils. Fresh water became a more critical factor for both game animals and the hunters who stalked them as solar warmth increased. Late Paleo-Indian period sites dating to after 10,000 BP are relatively rare in Delaware and in the mid-Atlantic region in general. The known sites are often small and ephemeral indicating a transitory occupation, and a low population density (Custer 1989:120-121).

Early Holocene: 10,000 - 6,000 BP

The numbers of spruce trees on the landscape had declined in the Middle Atlantic region by 10,000 BP. Spruce and fir trees were replaced largely by pines and oaks (Gaudreau 1988). The somewhat late

FIGURE18

Extinct Mastodon



The mastodon and other large ice-age mammals became extinct before 10,000 years ago because of climate change, and perhaps because Paleo-Indians over-hunted them.

decline of spruce tree populations may have been due to a cool, maritime climate east of the Appalachian Mountains that ended when the Atlantic Oceans's Gulf Stream shifted northward (Delcourt and Delcourt 1984:280).

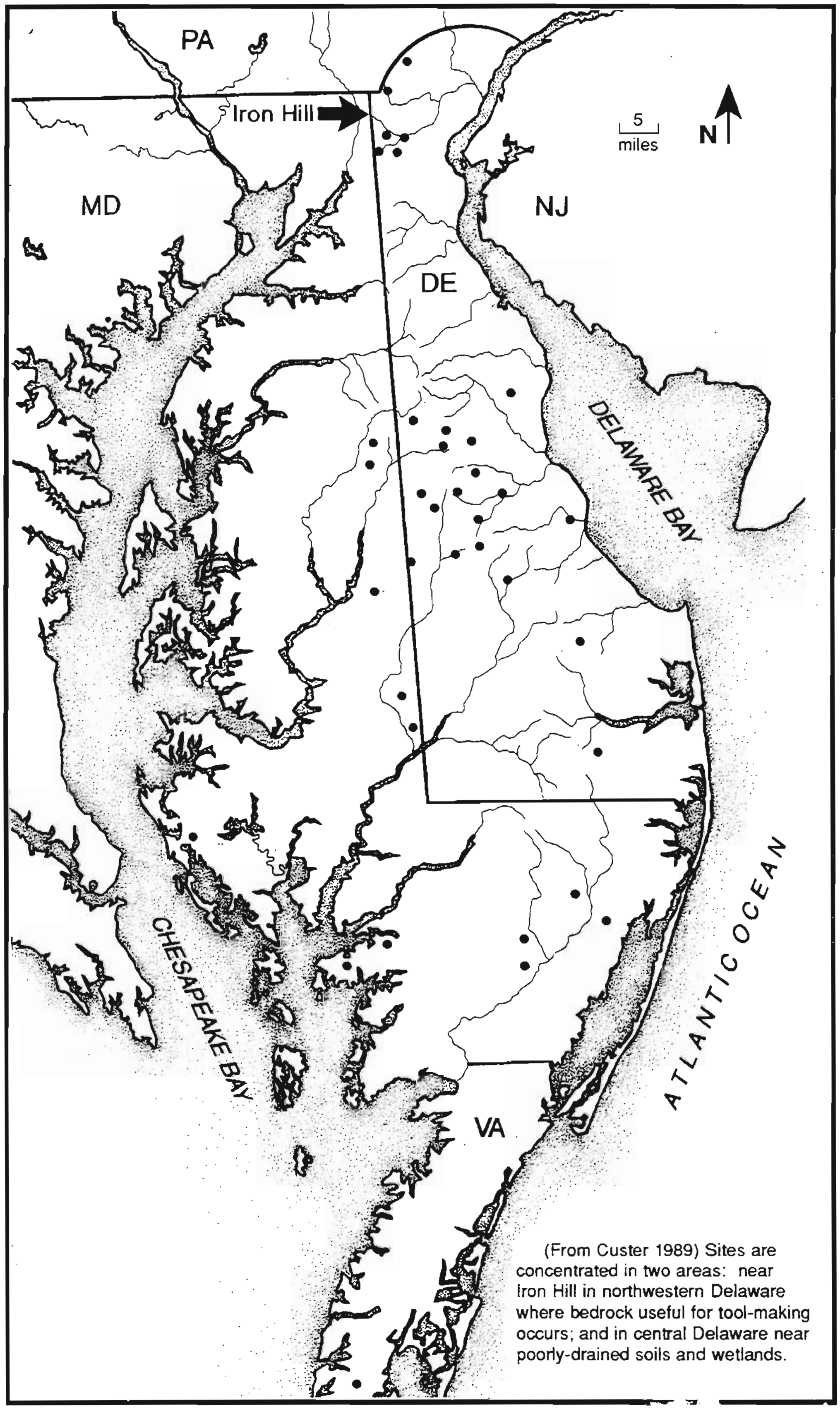
From 10,000 to 8000 BP a mixed forest of pines and oaks dominated the Middle Atlantic region. Oak populations expanded east of the Appalachians after 10,000 BP (Gaudreau 1988). At Rockyhock Bay in North Carolina (Whitehead 1981) water levels had dropped about 10,000 BP. The climate of the Mid-Atlantic region became drier as the edge of the ice sheet retreated north into Canada and as solar warmth increased. Watts (1979:463) concluded that the drier climate along the Atlantic coast and in the Appalachian mountains from before 8000 BP to about 5500 BP was dominated by oak tree species.

The history of pine trees along the Atlantic seaboard is difficult to interpret from the pollen evidence because there are so many different pine species and their pollen is so similar (Gaudreau 1988; Watts 1979:462-463). Gaudreau (1988:238-239) found that three population centers of pines developed between 10,000 and 6000 BP. Each of the areas was apparently dominated by different species of pine trees: southern varieties, northern varieties, and a coastal plain mixture adapted to drier conditions. Watts (1979:462-463) found early migrations of pine species northward, then a drop in pine populations along the mid-Atlantic coast. Finally pine populations expanded again in the late Holocene.

The beginning of the Archaic period in Delaware is marked by major changes in human adaptations (Custer 1989:122). By 8,500 BP solar radiation had reached a maximum and northern species of plants

FIGURE 19

Paleo-Indian Site Distribution on the Delmarva Peninsula



(From Custer 1989) Sites are concentrated in two areas: near Iron Hill in northwestern Delaware where bedrock useful for tool-making occurs; and in central Delaware near poorly-drained soils and wetlands.

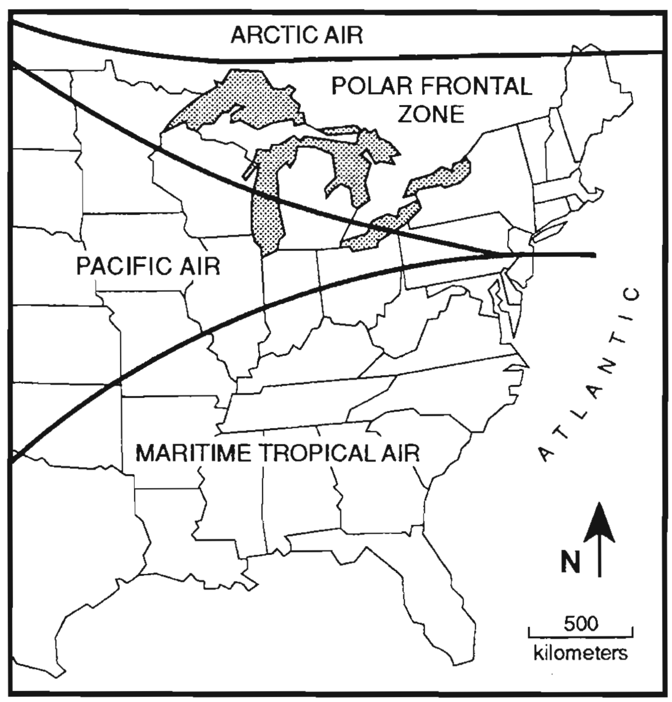
and animals had migrated northward out of the Mid-Atlantic region. Temperate plant and animal species were more common, and climate patterns had become more like those of the present. Few Archaic period archaeological sites have been excavated in Delaware, so what is known is extrapolated from other areas (Custer 1989:127-129). The major change in the archaeology is a wider variety of tools in the Archaic tool kit, especially plant processing tools. Archaic period peoples exploited a wider array of plants and animals than did the Paleo-Indian inhabitants of Delaware. Archaic period sites appear to have been occupied for longer periods of time, perhaps on a seasonal basis by flexible kinship-based groups (Custer 1989:129). Site distribution maps for the Delmarva Peninsula (Custer 1989:132) show that swamp settings were still preferred by people using bifurcate-base type stone points that date to before about 7,500 BP. Exchange of stone tools tied together people across large areas of the eastern United States providing a basis for the more elaborate exchange networks established later (Custer 1989:140).

Middle and Late Holocene: 6,000 BP - Present

Oak trees remained an important component of the vegetation of the mid-Atlantic region throughout the last 6000 years, but pines were expanding to the south along the Atlantic coast in the last 2000 years (Gaudreau 1988). Southern pines expanded as sea level approached present levels perhaps because water tables rose as well. A cooler and wetter climate also contributed to the expansion of pines after about 5500 BP (Watts 1979). The leaching of soil nutrients on the sandy, well-drained coastal plain may also have favored pines over deciduous tree species in the past 6000 years along the southern Atlantic coastal plain (Watts 1979:463). Hickory, an important species in the present forests of the mid-Atlantic, was a late arrival expanding out of the southeastern U.S. to reach the Delmarva area after 6000 BP (Jacobson, Webb, and Grimm 1987).

FIGURE 20

Present Climate Zones in the Mid-Atlantic



(From Delcourt and Delcourt 1987a) The Delmarva Peninsula is in a transition zone, thus our weather is highly variable, and susceptible to climate change

Archaeological studies suggest that the climate of the Delmarva Peninsula and New Jersey coastal plain after 5000 BP was quite variable (Curry and Custer 1982; Custer 1989:176-184; Custer and Watson 1987; Stewart 1983). Woodland period archaeological sites have been found buried below wind-blown sediments, which shows that the climate was still relatively dry and forest cover in the region was not complete. Fresh water was apparently a critical resource, so prehistoric people frequently camped near ephemeral ponds (Custer and Bachman 1986b).

The Delmarva Peninsula is in a transitional area between the northeast trending Appalachian highlands and the Atlantic coast and also between broad latitudinal climate zones (Figure 20; see Delcourt and Delcourt 1984; Kutzbach 1987; Watts

1979; Jacobson, Webb, and Grimm 1987). The Holocene climate history is difficult to infer from broad regional reconstructions based on pollen studies from swamps on the southeastern coastal plain and bogs and lakes in the Appalachian highlands. The mountain altitudes show their effects on the local climate in the pollen evidence (Gaudreau 1988) and the southern Atlantic coast is dominated by different air masses than the northern mid-Atlantic coast including Delaware (Delcourt and Delcourt 1984; 1987a, 1987b).

Most published studies on vegetation and climate along the Atlantic coast of the United States emphasize the radical changes in climate and vegetation following the end of the last ice age (for example, Delcourt and Delcourt 1984, 1987a, 1987b; Jacobson, Webb, and Grimm 1987; Watts 1979, 1983; Webb, Bartlein, and Kutzbach 1987; Whitehead 1973). Holocene changes are less dramatic and more idiosyncratic and local (Gaudreau 1988; Webb, Bartlein, and Kutzbach 1987). The lack of ideal localities for pollen study on the Middle Atlantic coastal plain, especially on the Delmarva Peninsula and the Jersey coastal plain, leaves a gap in the local vegetation and climate history for the area over the last 10,000 years. A complete Holocene pollen diagram for the coastal plain north of the Dismal Swamp does not, and may never, exist. Thus, many questions remain about the vegetation and climate of the Delmarva Peninsula and New Jersey coastal plain.

The studies contained in this report were carried out to help fill the gap in paleoenvironmental data available for the Delmarva Peninsula and clarify our understanding of the environments in which people lived in the past and in which prehistoric societies developed and changed over the course of centuries. The studies are part of the larger project and more work is being undertaken to provide more detail at locations of intensive prehistoric settlement. Paleoenvironmental reconstructions are constantly being revised and improved as more data becomes available. The reports here are steps along the path to recreating the landscapes of Delaware's past.

The prehistory of the last 5000 years is divided into two archaeological time periods: the Woodland I and the Woodland II. The end of the Archaic period and beginning of the Woodland I at 5000 BP is marked by dramatic changes in prehistoric cultures (Custer 1989:141-144). Archaeological sites of the Woodland I period are more abundant, larger, and more complex than earlier sites. Social organization became more complex with some individuals achieving high status and power. Trade and exchange networks became more formal and more extensive than during the Archaic period. Material culture became more diversified also. First, soapstone bowls and then, ceramics were introduced into the region. A wide variety of chipped stone tools were used. Regional variations in tool kits and life ways are also evident in the archaeology of the Woodland I period (Custer 1989:141-144).

Coastal resources were more intensively exploited in the Woodland period than they had been previously (Custer 1988). The rate of sea-level rise had slowed so that large coastal wetlands could develop and shellfish populations expanded. Tidal streams became the focus of Woodland I settlement, and large clusters of archaeological sites are found below the head of tide along these streams. The State Route 1 corridor crosses several tidal streams near the head of tide and the archaeological sites that are being studied are located there (Custer, Bachman, and Grettler 1987; Bachman, Grettler, and Custer 1988). The studies by Rogers and Pizutto, and by Brush in this volume were conducted along such tidal streams.

The beginning of the Woodland II period is marked by important changes in prehistoric life (Custer 1989:298-300). Settlement patterns changed; trade and exchange networks broke down; and agriculture was introduced. Settlements became more permanent, and the life style was more sedentary. The break down of trade networks is clearly seen in the types of stone used to make tools. Exotic raw materials are rare in Delaware after about AD 1000. Evidence for domesticated plants in Delaware is rare, suggesting that although crops were tended, wild plant foods were still important in the prehistoric diet. A more sedentary life style did allow larger villages to develop and more permanent houses were constructed. Environments during the Woodland II were probably very similar to those of the present.

Native American life was permanently disrupted by contact with European explorers and colonists starting about AD 1600 in the Middle Atlantic (Custer 1989:332-335). Some groups thrived for a time, trading furs and tobacco for European goods, but ultimately disease, political strife, and cultural disintegration ended in the virtual extinction of Native Americans in Delaware.

POLLEN AND SEDIMENT RECORDS FROM WALTER'S PUDDLE IN CENTRAL DELAWARE

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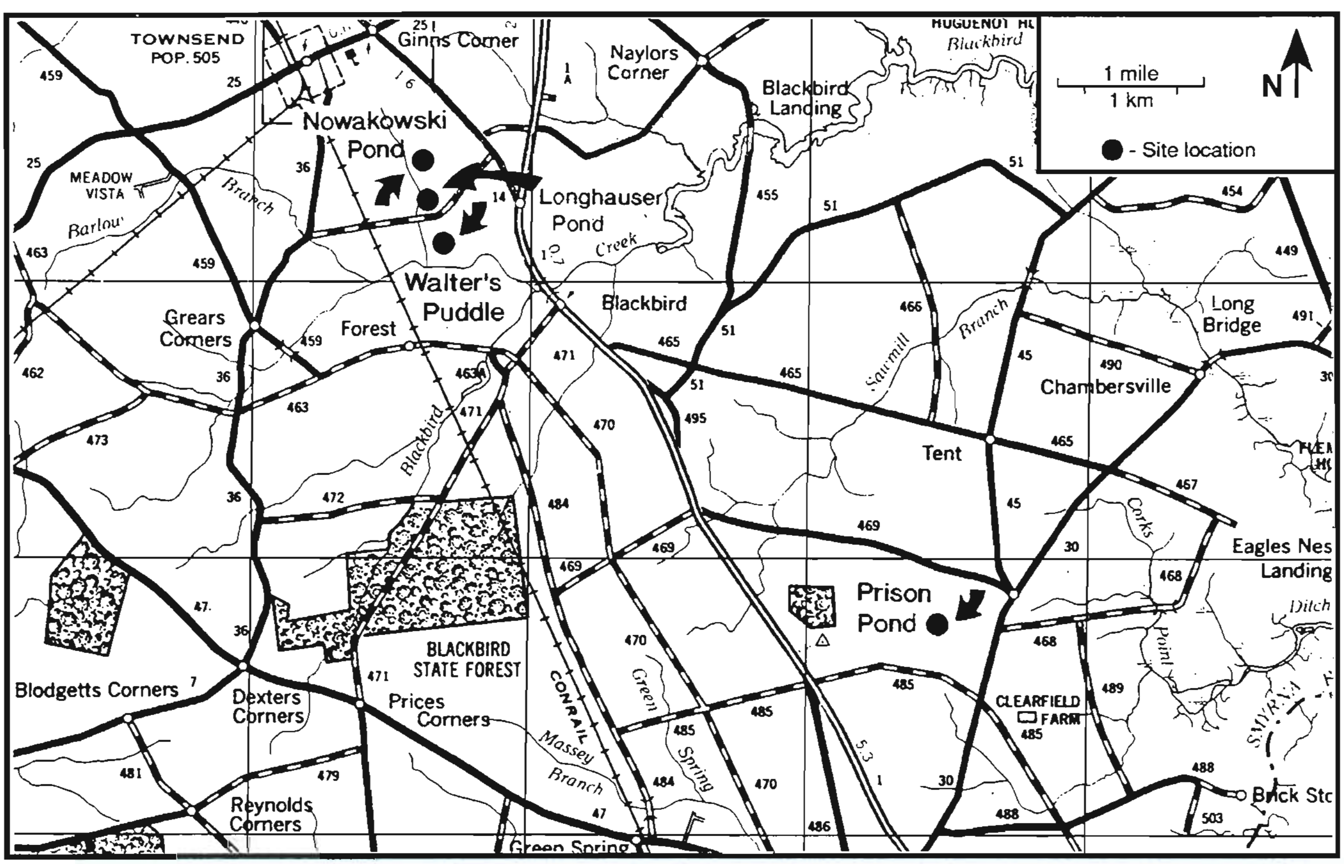
INTRODUCTION

Walter's Puddle (39°22' 53" N, 75°40' 33" W) is a small, oval basin near Townsend, Delaware (Figure 21). The area surrounding the basin supports a forest dominated by oak (Quercus), beech (Fagus), and tulip (Liriodendron) trees with an understory of sassafras (Lauraceae, Laurel Family), huckleberry (Vaccinium) and buttonbush (Cephalanthus). We did not observe any pine (Pinus) trees in the immediate

FIGURE 21

Location of Bay/Basin Ponds Studied



Bay/basin ponds are very common in this area of the Delmarva Peninsula area. The modern climate of this region is temperate and is seasonally dominated by Arctic, Pacific and maritime Tropical air masses (Bryson 1966; Bryson and Hare 1974; Wendland and Bryson 1981). The size and position of the Atlantic high pressure cell (the subtropical high pressure anticyclone located over the mid-latitudes, 30° to 3°°N, of the Atlantic Ocean) influences atmospheric circulation in this region (Ruffner 1985). In winter months, the Atlantic anticyclone retreats eastward, and storm systems, generated by a contrast between cold Arctic air and moist maritime Tropical air, result in cold and wet climate conditions. In summer months, the Atlantic anticyclone expands north and westward resulting in an anticyclonic circulation pattern that brings warm, moist, maritime Tropical air into the region. The extended presence of the Atlantic anticyclone over the region during the summer can result in drought because:

1) storm tracks shift west and northward, and

2) the descending dry, cooler air associated with the sub-tropical high precludes precipitation in favor of evaporation (Ruffner 1985).

Walter's Puddle is located in the high coastal plain physiographic region (Custer 1984a) in northern Delaware near other small, enclosed depressions of undetermined origin. The widespread geographic distribution of similar basins (the Atlantic Coastal Plain from New Jersey to Florida) makes it difficult to identify any single geologic process as responsible for the formation of these basins. Northern Delaware was south of the ice sheet during the Wisconsin glacial maximum, and the origin of these and similar basins may be related to periglacial and/or thermokarst processes (Watts 1979). Further south, studies of Pleistocene geomorphic features on the Coastal Plain of South Carolina suggest that wind may have shaped similar basins in this area and that they were formed during the last glacial maximum (Thom 1967 in Whitehead 1973). An extensive study of the geology and hydrology of basins in Delaware suggests a "basin to bay" formation sequence from a combination of free ground water and wind processes (Rasmussen 1958).

METHODS

Field Operations

In June, 1985, we collected two sediment cores for palynological analysis as part of the archaeological planning survey of the proposed State Route 1 corridor in Kent County, Delaware (Plate 1). Dr. Jay Custer suggested Basin B (Walter's Puddle) as a possible location for study because it was in close proximity to archaeological sites and appeared to contain water throughout the year. Trees were growing on the periphery of the basin as well as in the basin indicating that water levels were high at the time of coring. A two-inch Livingstone piston corer was used to obtain a 4.04 m core (Core B) of sediment in one meter sections from the center of the pond at a water depth of 85 cm. The basal stratigraphy of the core may not represent the bottom surface of the pond because the clay content of the sediments made the coring process difficult. Our first coring attempt was unsuccessful, and we abandoned Core A due to extrusion difficulties and weather conditions. Core B was extruded in the field, described, labeled, wrapped in plastic and aluminum foil and secured in aluminum flashing.

Laboratory Processing

The sediments were described in terms of changes in color, texture, lithology, and presence of macrofossils (Table 3). Contiguous 1 cc samples were taken for weight loss on ignition (Dean 197[illegible]) and

PLATE 1

Coring Walter's Puddle

The crew is using a Livingstone corer from a raft to retrieve an undisturbed sample of the pond's mud.

TABLE 3

Description of Core B: Walter's Puddle, Townsend, DE

Depth (meters)	Description
0.00 - 0.13	Silty/sandy, organic lake mud: black (7.5YR2/0); detrital component (leaf molds), more coherent with increasing depth.
0.13 - 0.30	Clayey/silty, organic lake mud: dark black-brown (10YR2/1); slightly to semi-plastic.
0.30 - 0.40	Missing. Fibrous, detrital component (leaf fragments).
0.40 - 0.53	Silty/clayey, organic lake mud: black (10YR2/1); slightly sticky, non-plastic.
0.53 - 0.62	Silty, organic lake mud: black (5Y2.5/2); slightly sticky, non-plastic.
0.62	Sharp contact.
0.62 - 0.90	Silty, fine grain sand: very dark grayish brown (2.5YR3/2).
0.90 - 1.06	Clayey silt: very dark grayish brown (2.5Y3/2).
1.06 - 1.37	Silty clay: very dark gray (5YR3/1); highly plastic.
1.37 - 1.40	Missing.
1.40 - 1.89	Silty clay: black (5Y2.5/2).
1.89 - 1.99	Silty clay grading into slightly silty clay: black (Y2.5/2).
1.99 - 2.18	Slightly silty clay: black (5Y2.5/2): plastic, slightly sticky.
2.18 - 2.33	Missing.
2.33 - 2.66	Sandy/silty clay: very dark gray (Y3/1); highly plastic.
2.66 - 2.99	Sandy/silty clay: dark olive gray (5Y3/2); highly plastic.
2.99 - 3.06	Missing.
3.06 - 3.16	Silt: dark olive gray (5Y3/2).
3.16 - 3.21	Silty sand: dark olive gray (5Y3/2).
3.21 - 3.23	Silt: dark olive gray (5Y3/2).
3.23 - 3.27	Silty sand: dark olive gray (5Y3/2).
3.27 - 3.31	Silt: dark olive gray (5Y3/2).
3.31 - 3.33	Silty sand: dark olive gray (5Y3/2).
3.33 - 3.37	Silt: dark olive gray (5Y3/2).
3.37 - 3.46	Sand: very dark gray (5Y3/1).
3.46 - 3.48	Silt: olive gray (5Y4/2).
3.48 - 3.50	Clay: olive (5Y5/3).
3.50 - 3.56	Sandy clay: olive (5Y5/3).
3.56 - 3.59	Silty clay: olive gray (5Y4/2); banding (rhythmites) of lighter and darker colored material approximately 1 mm thick, irregularly alternating lithology.
3.59 - 3.60	Sand lense: olive gray (5Y4/2).
3.60 - 3.64	Clayey silt: olive gray (5Y4/2); banding (rhythmites) of lighter and darker colored material approximately 1 mm thick, irregularly alternating lithology.
3.64 - 3.66	Fine sand: olive gray (5Y4/2); banding (rhythmites) of lighter and darker colored material approximately 1 mm thick, irregularly alternating lithology.
3.66 - 3.74	Clayey silt: olive gray (5Y4/2); banding (rhythmites) of lighter and darker colored material approximately 1 mm thick, irregularly alternating lithology.
3.74 - 3.81	Clayey silt: olive (5Y4/2).
3.81 - 3.85	Sandy clay: olive (5Y4/3); mottled color and texture.
3.85 - 3.94	Clayey silt: bluish gray to dark bluish gray (5B4.5/1).
3.94 - 3.95	Clayey silt: very dark gray (2.4Y3/0); plastic.
3.95 - 4.04	Silt: olive gray (5Y5/2).

for pollen analyses at selected intervals in the core. We used our knowledge of the sediment stratigraphy (Appendix I) to select the samples. The processing of the samples for pollen analysis followed the standard procedures for the removal of unwanted organic material (KOH), carbonate (HCL) and silicate (HF) (Faegri and Iversen 1975). The samples were also screened to remove large "sand" grains and treated with sodium pyrophosphate to remove clay size particles (Bates, Coxon and Gibbard 1978). The residual was mounted on microscope slides in silicon oil, and the pollen grains were identified using a magnification of 400x.

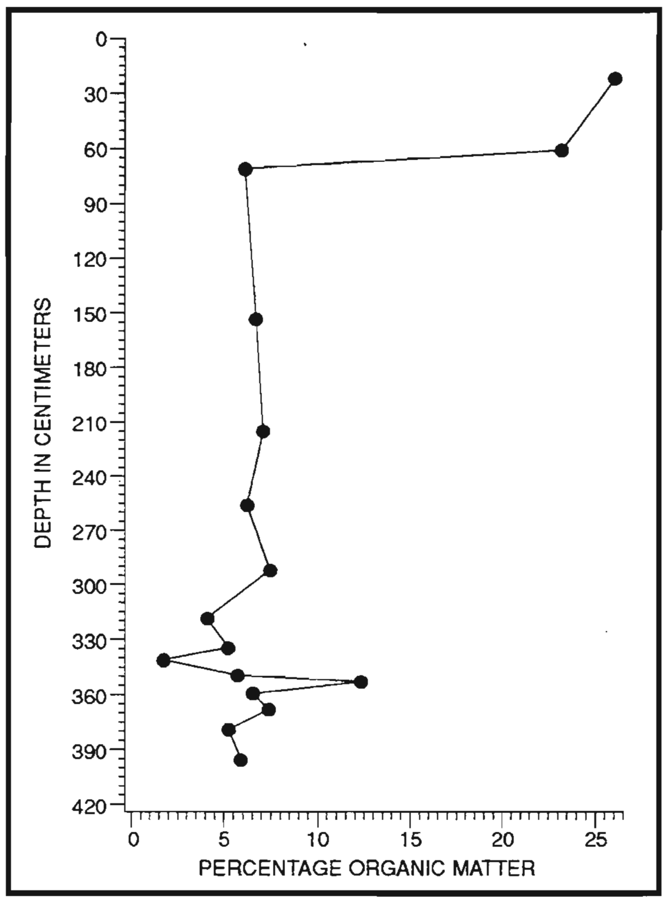
RESULTS

Stratigraphy

The core sequence from Walter's Puddle included dark, more organic sediments at the top of the core grading to predominantly sand, silt, and clay with gradational textural and color boundaries at the bottom. The sediment graded from a loose, flocculent consistency (0-13 cm depth below sediment water interface) to a slightly hard, plastic consistency to the bottom of the core. Abrupt changes in sediment stratigraphy in sections 2 and 5 suggested changes in water depth during the basin's history. In section 2, there was a sharp contact with rip-up clasts between 61 and 63 cm suggesting a hiatus in sediment accumulation (Plate 2). The rip-up clasts at the hiatus contact may be the result of desiccation. Section 5 (306-384 cm) contained abrupt sedimentary changes that included an incoherent, poorly sorted sand lens (337-346 cm), a mottled sandy clay interval (350-354 cm) and rhythmites (358 to 374 cm). Section 5 also contained a few small sand lenses. These changes suggest dry intervals for at least a portion of the basin's earlier history. The poorly sorted sand lens (337-346 cm) suggests some abrupt change in the deposition that may relate to the movement of surface material. The rhythmites (approximately 1 mm wide) had irregular textures and were defined by different colors. The rhythmites may indicate some short term fluctuations in deposition that reflect intermittent changes in water levels. Fungal hyphae, produced in a subaerial environment, were observed in the lower sediments of the core, and also suggest dry intervals at the basin.

FIGURE 22

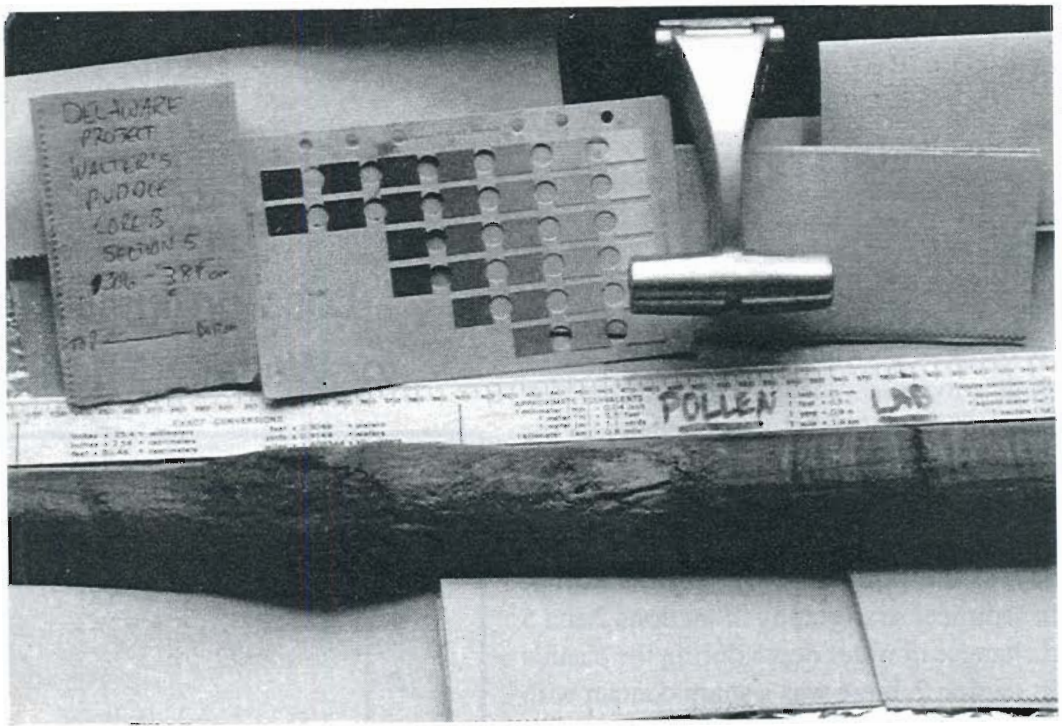
Loss-on-Ignition Plot for Walter's Puddle Core



Loss-on-ignition gives an estimate of the percentage of organic matter (by weight) in a sediment sample.

The percent organic carbon increased from 6.16% to 23.3% between 58.5 and 61.6 cm at the change from lighter, more plastic material to darker, less coherent sediments (Figure 22). Radiocarbon dates were obtained from depths of 52-60.75 cm (5820±80 BP, WIS-1802), 62.75-69 cm (11,880±160 BP,

PLATE 2
Stratigraphy of a Bay/Basin Core



The gray section is a gap in the organic-rich deposition in the pond.

WIS-1803) and 109-116 cm (14,400±160 BP, WIS-1804) below the sediment water interface. We selected two dates from depths between 52 and 69 cm to bracket the hiatus suggested by loss on ignition values (Figure 22), and sediment and pollen stratigraphies. The lower date was taken for additional chronostratigraphic information for the core. We do not have enough data from Walter's Puddle to comment definitively on the processes and timing of its origin. Initial comparisons of the shape, orientation and sediments from Walter's Puddle with the detailed studies of basins in the adjacent Clayton Quadrangle (Rasmussen 1958) indicated some similarity.

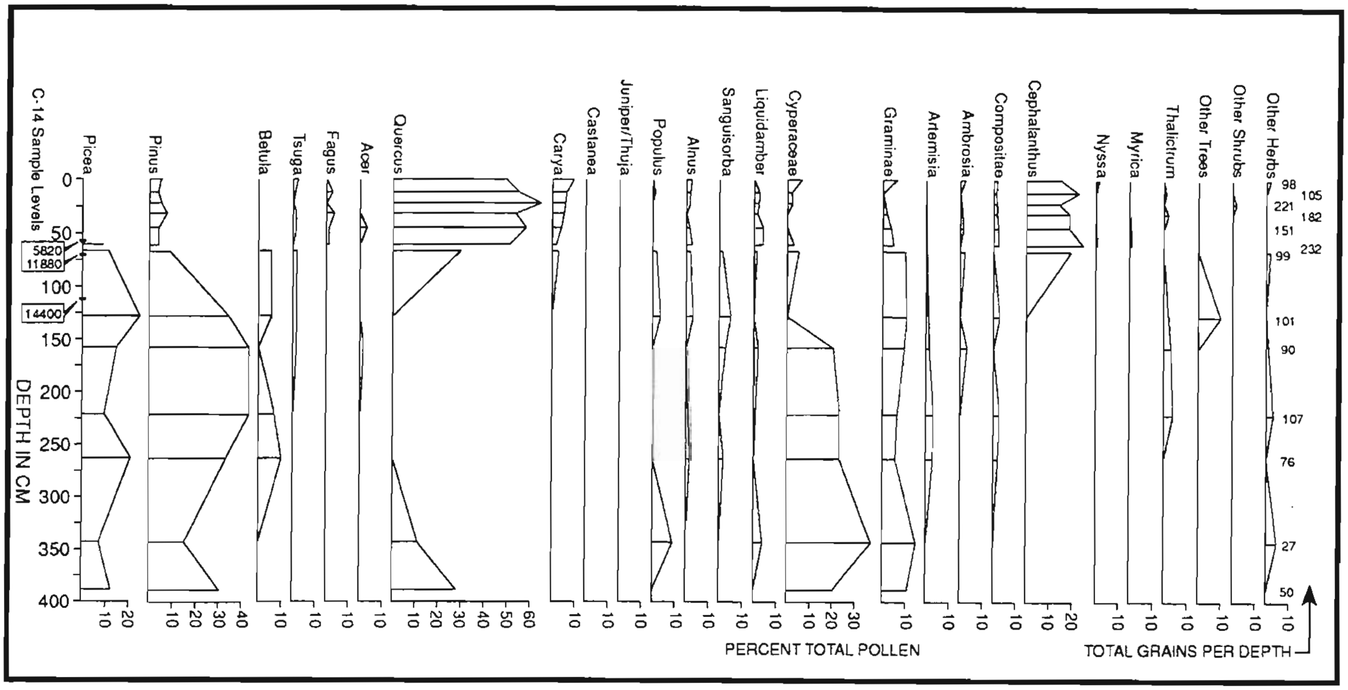
The Pollen Diagram

The pollen diagram (Figure 23) from Walter's Puddle can be divided into three major zones: Walter's Puddle-3 (WP-3) characterized by spruce (Picea), oak and sedge (Cyperaceae, Sedge Family), Walter's Puddle-2 (WP-2) characterized by spruce, pine, birch and sedge and Walter's Puddle-1 (WP-1) dominated by oak and buttonbush (Cephalanthus).

Walter's Puddle-3 [Spruce-Oak-Sedge]. The pollen assemblage from the lowest zone of Walter's Puddle (404-300 cm) was characterized by poor preservation and low concentrations. Most of the identifiable pollen (pine, oak and sedge) was broken and/or degraded. Other pollen taxa present were poplar (Populus), grasses (Gramineae, Grass Family) and a single grain from the Mustard Family (Cruciferae). The pollen

FIGURE 23

Walter's Puddle Pollen Diagram



counts for samples from this zone were low (<100 grains). These low counts make the description of the pollen composition tentative at best.

Walter's Puddle-2 [Spruce-Pine-Birch-Sedge]. The pollen assemblage from this zone (300 to 61 cm) was characterized by high percentages of spruce, pine, birch and sedge. Spruce pollen percentages fluctuated between 10% and 25% and pine pollen percentages peaked at 44% in this zone. Hickory (Carya) and buttonbush pollen percentages occurred for the first time in the core at 63.5 cm. In the same level, oak pollen percentages were 30%. No oak pollen was found in any other level of WP-2. Maple (Acer), hemlock (Tsuga) and poplar pollen percentages were less than 2%. Rosaceae (Sanguisorba) and Artemisia (Compositae, Aster Family) pollen also occurred for the first time but their values were less than 5% throughout the zone. Sedge pollen percentages were high (23%) at the base of this zone, then declined to less than 5% from 122.5 cm to the top. Alder (Alnus,) Sweetgum (Liquidambar), ragweed (Ambrosia) and composite (Compositae, Aster Family) pollen percentages each occurred at <5%. Grass pollen percentages were high and peaked at 11% in the upper levels of this zone.

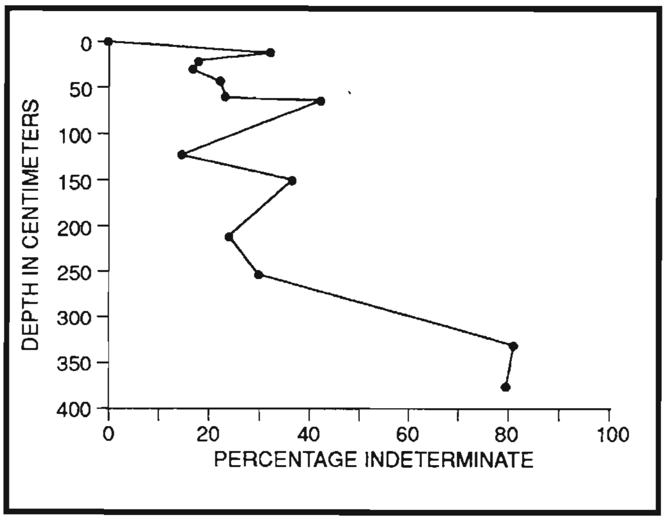
Walter's Puddle-1 [Oak-Buttonbush]. The pollen assemblage from this zone (61 cm to 0 cm) was dominated by high values of oak pollen (>50%). Pine pollen percentages declined from peak values (>40%) in WP-2 to less than 10%. Hickory pollen percentages gradually increased from 2% to 10%. Birch, beech, maple, chestnut (Castanea) and poplar were each less than 5% of the total assemblage. Spruce and Artemisia pollen percentages were negligible (less than 1% total) and Sanguisorba pollen did not appear. Buttonbush pollen percentages were high (>15%) and sweetgum and alder pollen were both present at less than 5% throughout the zone. Myrica (Myricaceae, Bayberry Family) and blackgum (Nyssa) pollen percentages were less than 2% of the total assemblage. Ragweed and other herb pollen percentages rose slightly at 10.5 cm, while other herbaceous pollen (sedge, grasses, meadowrue (Thalictrum) occurred throughout WP-1.

DISCUSSION

The data from Walter's Puddle provide information on changes in depositional regimes, vegetation and water-levels fluctuations. The radiocarbon dates indicate that deposition may have begun before the last glacial maximum, (i.e., before 18,000 BP) and that a hiatus is present in sedimentation from 11,880 to 5,800 BP.

The pollen assemblage from the WP-3 was probably the result of differential preservation due to poor preservation and low pollen concentrations: greater than 50% of the pollen assemblage was indeterminate (Figure 24) and the pollen concentrations were less than 10,000 grains per/cc (Figure 25). However, the presence of oak pollen with spruce and sedge suggests that the lowest sediments in the core may date to the mid-Wisconsin interstadial (about 23,000-36,000 BP). In the pollen stratigraphies from Ninepin 24, Delmarva Peninsula (Sirkin, Denny and Rubin 1977) and Rockyhock Bay, North Carolina (Whitehead 1981), oak pollen percentages were higher during the mid-Wisconsin interstadial and then declined to low percentages during the late and full glacial period. The presence of oak pollen in WP-3 and its absence from WP-2 suggest a similar sequence for the glacial sediments at Walter's Puddle. This change could also be the result of differential preservation and low concentrations. The low pollen counts for samples in this zone make these conclusions tentative.

FIGURE 24
Indeterminate Pollen Counts for Walter's Puddle

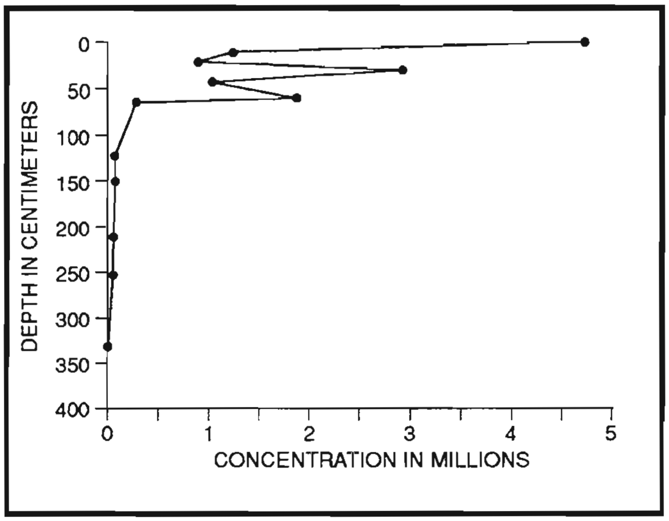


Indeterminable pollen grains result from mechanical damage by exposure to air and by redeposition.

Two radiocarbon dates (Figure 23) from WP-2 indicate a late glacial age (14,400 to 11,880 BP) for the sediments from 122 to 61 cm. The sediments from 300 to 116 cm are older than 14,400 BP and are probably of full-glacial age. Spruce, hemlock, pine and birch (probably shrub birch, B. glandulosa) with more northern herb pollen such as Sanguisorba and sedge suggest that boreal vegetation grew near Walter's Puddle during this time. Spruce/Sanguisorba pollen assemblages in regional pollen stratigraphies from unglaciated locations north of Walter's Puddle indicate vegetation that may have resembled a forest tundra, with areas of spruce (probably P. glauca) mixed with shrubs (especially dwarf birch) and wet meadows with tall herbs such as Sanguisorba (Watts 1979). Low pollen percentages from temperate deciduous trees in zone WP-2 suggest that they did not grow near Walter's Puddle at this time and higher pollen percentages of sedge and non-arboreal pollen (NAP) in the lower stratigraphy of WP-2 may represent a more open environment or more local pollen input into the basin. The vegetation at Walter's Puddle probably differed from the vegetation at the more northern locations at this time (about 14,000 BP) as climate change and deglaciation affected the abundance and composition of plant populations differently. Further work on the stratigraphy from Walter's Puddle will help define regional vegetation south of the ice sheet and local vegetation in the area during the full and late glacial period.

FIGURE 25

Pollen Concentration for Walter's Puddle



Two radiocarbon dates (62.75 cm - 69 cm: 11,880 BP, and 52 cm - 60.75 cm: 5820 BP) confirmed a hiatus between the late glacial and the middle Holocene in the sediment record from Walter's Puddle. A sharp, diagonal contact (61 cm to 63 cm) and a change from dark, silty lake muds to silty, fine grain sands bracketed the hiatus in the core. This depositional break was also suggested by changes in the pollen stratigraphy between the oak-buttonbush (WP-1) and spruce-pine-birch-sedge (WP-2) zones (Figure 23). Oak, hickory, and buttonbush pollen percentages at 63.5 cm in WP-2 and a radiocarbon date of 11,800 BP at the hiatus indicate some sediment mixing, and the presence of rip-up clasts is consistent with the possibility of vertical sediment mixing.

The hiatus could be the result of missing sediments that were never deposited (disconformity), or sediments that were periodically eroded or oxidized prior to deposition of overlying materials (unconformity). Studies of the water level, specific yield and permeability of similar basins in Delaware indicated that they are subject to periodic water fluctuations that change water levels in the basins (dry to semi-permanent to ephemeral ponds) seasonally and in relation to droughts (Rasmussen 1958). The degraded condition of the pollen (Figure 24) and the low organic content of the sediments (Figure 22) below 63 cm suggest that oxidation took place during intermittent dry periods at Walter's Puddle during the late Pleistocene. We do not have enough data to determine why sediment began accumulating again about 5820 BP at the basin, nor is it evident that there has been constant sediment accumulation since then (approximately 10 cm every 1000 years).

The Holocene pollen stratigraphy from Walter's Puddle indicates that an oak forest already dominated the area around the basin by 5800 BP. Birch, beech, maple and hickory were also in the forests. Alder, sweetgum and buttonbush shrubs and trees, characteristic of wetter habitats, probably surrounded the basin. Grass, sedge, and Thalictrum possibly grew intermittently on the basin during periods of lower water levels. Excellent pollen preservation (Figure 24) and high pollen concentrations of greater than two million grains per/cc (Figure 25) suggest local as well as regional input of pollen to the basin during this time.

SUMMARY

The pollen analysis of a 4.04 m core from Walter's Puddle, Delaware documents a history of vegetation changes that may have begun in the late Pleistocene with a pine, oak and sedge vegetation, followed by a spruce, pine, birch and sedge assemblage during the full- to late-Wisconsin glacial period. A hiatus occurs in the stratigraphy (approximately 62 cm) from the late glacial (11,880 BP) to the middle Holocene (5820 BP). The Holocene pollen stratigraphy records a regional oak-dominated forest with a local representation of vegetation characteristic of bog habitats.

PALYNOLOGY AND PALEOHYDROLOGY OF DELAWARE

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INTRODUCTION

The sediment records from small basins can yield information on the paleohydrology of an area. Previous work at Walter's Puddle in central Delaware has documented changes in the water level of the basin (Newby, Webb, and Webb in this volume; Figure 21). The pollen record, the sediment stratigraphy, and the radiocarbon dates from a core taken in the center of Walter's Puddle near Townsend, DE, independently confirm the existence of a major hiatus (unconformity) within the basin. We interpret this hiatus, dated from 11,880 to 5820 BP, to be a period of lowered water levels. Under these conditions, the basin dried out and sediments were desiccated and removed. Before 11,900 and after 5800 BP the accumulation of sediment in the basin appears to have been relatively continuous during periods of higher water levels in the basin. After the initial work at Walter's Puddle, important stratigraphic questions concerning the duration, magnitude, and regional extent of this early to mid-Holocene drop in water level remained unresolved, however.

The bracketing dates of 11,880 and 5820 BP have provided a maximum estimate for the period of lowered water levels at Walter's Puddle. The 5820 BP date is a well-constrained estimate for the end of lower water level conditions in the basin, whereas, the 11,880 BP date for the beginning of lowered lake level is less well-constrained. Because the hiatus was probably an erosional surface, the sediments immediately below the hiatus are more likely to represent the stratigraphic depth to which material was removed during lowered water level conditions than the material deposited immediately before the onset of such conditions. Previous work has been unable to resolve whether the lowered water levels at Walter's Puddle lasted 6000 years (11,880 to 5820 BP) or less than 1000 years (6800 to 5820 BP).

The extent and nature of the erosional surface within Walter's Puddle also was not well-constrained from our initial field work. From a single 5 cm diameter sediment core, we were unable to predict whether the erosional surface was continuous and uniform within the basin. We did not find additional evidence that could provide insights into the drying out process such as soil development within the basin, presence of a subsurface bench suggestive of intermediate water levels within the basin, or desiccation surfaces indicative of the maximum drop in water level. Finally, we wanted to know whether the period of lowered water level at Walter's Puddle was unique to the basin or if it represented a regional drop in the water table. If the drop in water level at Walter's Puddle was symptomatic of a regional trend, the archaeological, paleoclimatic, and paleoecological significance of the event would be much more far-reaching.

To address these research interests, Walter's Puddle was recored following Digerfeldt's (1974) method of obtaining a transect of sediment cores within a basin to look for evidence of water level fluctuations. We took a transect of short-cores (1 m or less) from the center of the basin to the edge to sample the erosional surface/hiatus throughout the basin. We also cored three additional basins within the area following the Digerfeldt (1974) method of multiple-core transects. Two of these basins, Longhauser Pond (39°23' 05" N, 75°40' 30" W) and Nowakowski Pond (39°23' 09" N, 75°40' 40" W) were within 500 m of Walter's Puddle. The third basin, Prison Pond (39°20' 20" N, 75°36' 45" W), is located approximately 15 km south of Walter's Puddle in Smyrna, DE. (Figure 21). Evidence for a hiatus was found in each of the cores within the transect at each basin. Correlation of this hiatus between basins verified the regional nature of the water level fluctuation and further constrained the timing of this event.

STUDY DESCRIPTIONS

A total of 10 locations in the Smyrna to Townsend, DE area were surveyed as potential basins to be cored. All the basins were "bay/basins" - small, closed depressions of indeterminate origin (Plate 3). Newby, Webb, and Webb (in this volume) have provided a thorough description and discussion of the origin of this type of basin, the regional vegetation, and the modern climate of the area. For our second phase of field work, we selected three of the basins for coring. The basins, as well as Walter's Puddle, appeared to remain wet throughout the year.

Longhauser Pond

Longhauser Pond is a shallow, elongated oval basin approximately 75 by 40 m (Figure 26) with the long axis trending northeast/southwest. At the time of coring the maximum water depth was 55 cm. The center 30 m of the basin was open water, ringed by 10 m of emergent Cephalanthus (buttonbush), and a ring of 5 to 10 m of open water along the edge of the basin (Figure 26 and 27).

Nowakowski Pond

Nowakowski Pond is a shallow, elongated oval basin approximately 90 by 50 m (Figure 26). This basin, with the long axis trending northwest/southeast, appeared to be made up of two distinct, smaller sub-basins. Emergent Cephalanthus occupied most of the basin with only the center of each sub-basin containing open water. At the time of coring the maximum water depth was 45 cm (Figure 28).

Prison Pond

Prison Pond is a small, shallow, oval basin approximately 25 m in diameter. The maximum water depth at the time of coring was 55 cm. The center 10 m of the basin was open water, ringed by 10 m of emergent Cephalanthus, and an outer ring of 5 m of open water (Figure 26).

Walter's Puddle

Walter's Puddle is a small, oval basin approximately 20 m in diameter and 1 m in depth. The basin had been excavated by the owner since the original core was taken. The northwestern section of the basin was dug out 1 to 2 m with debris fringing the area of primary disturbance (Figure 26).

PLATE 3

Aerial Photograph of Bay/Basin Ponds

Many Bay/Basin ponds occur in central Delaware. Some hold water year round, while others are shallow and are plowed over by farmers.

FIGURE 26

Sketch Maps of Bay/Basin Study Localities

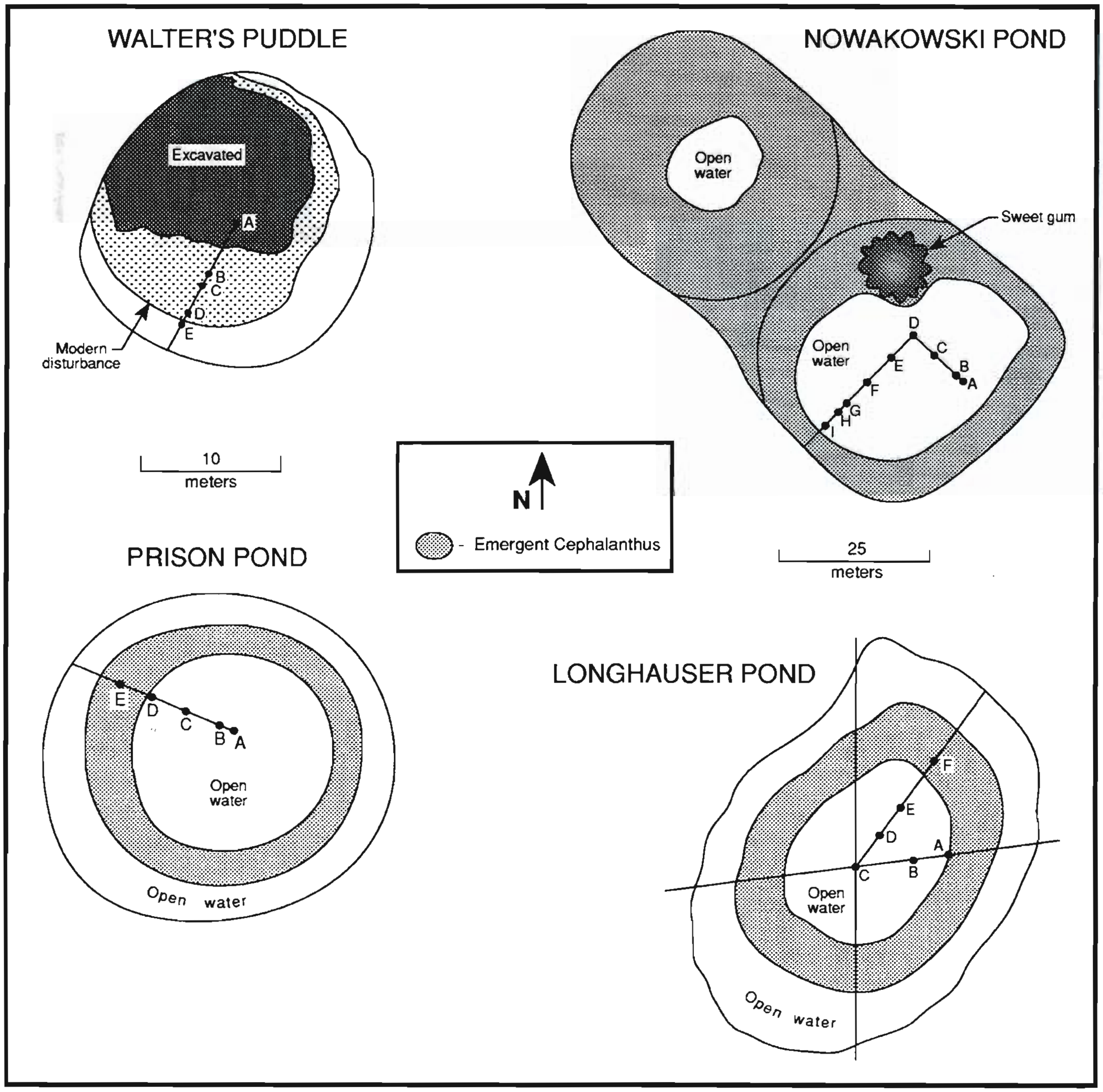


FIGURE 27

Stratigraphic Profile of Longhauser Pond

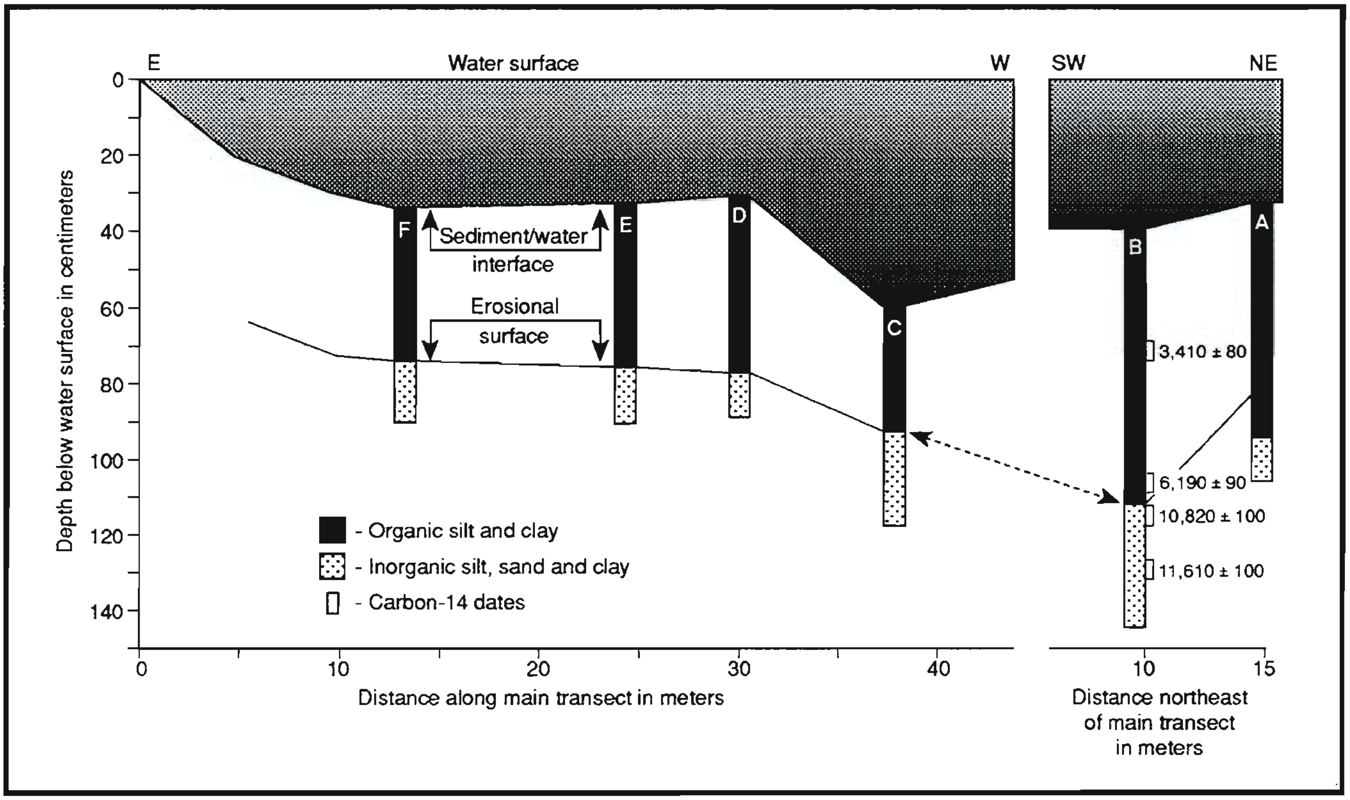
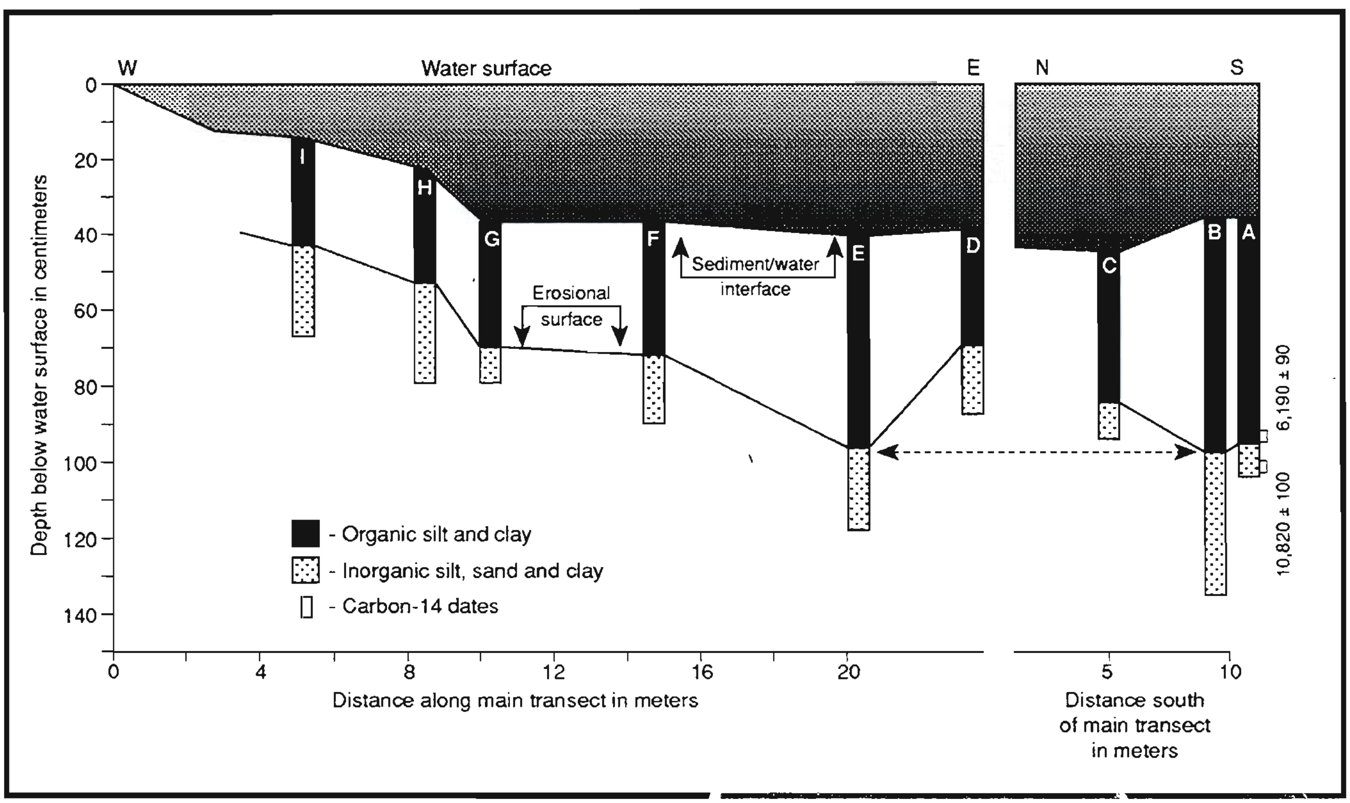


FIGURE 28

Stratigraphic Profile of Nowakowski Pond



METHODS

Field Work

Transects of cores were taken in each of the four basins extending from the shoreline to the center of the basins. The location and orientation of the transects of cores were selected to maximize:

1) sampling within each basin; and

2) recovery of as long a section of organic-rich sediments as possible.

Five centimeter diameter polycarbonate tubes with pistons were used to sample the upper 50 to 75 cm section of each core. These polycarbonate tubes were capped and extruded in the laboratory. To recover material below the depth of 50 to 75 cm, a modified 5cm Livingston piston corer was used. A 10 cm PVC tube with piston was also used to take a core along the transect in each basin for higher resolution radiocarbon dating. By increasing the surface area of the core, we hoped to decrease the amount of stratigraphic displacement required for each sample submitted for radiocarbon dating. These cores were also capped and extruded in the laboratory.

A total of six cores was taken at Longhauser Pond: four along a northeast/southwest transect, Cores C-F; and two along an east/west transect, Cores A and B (the 10 cm radiocarbon core; Figure 26). At Nowakowski Pond, nine cores were taken: six along a southeast/northeast transect, Cores D-I; and three along a north/south transect, Cores A (the 10 cm radiocarbon core), B, and C (Figure 26). Five cores were taken at Prison Pond along a east/west transect, Cores A-E (Figure 26). Four more cores were taken at Walter's Puddle along a northeast/southwest transect, Cores B-E (Figure 26).

Laboratory Analyses

Core sediments were described in terms of changes in color, lithology, texture, and relative abundance of macrofossil material. Samples were taken for loss-on-ignition at selected intervals (every 5 to 10 cm) in each of the cores. A total of twelve radiocarbon samples were submitted for analysis: four samples from Longhauser Pond, Core B; two samples from Nowakowski Pond, Core A; two samples from Prison Pond, Core A; and four samples from Walter's Puddle, Core B (Table 4). Each radiocarbon sample was wet-sieved using a 2-4 mm brass sieve to remove potential contaminants, such as rootlets, and then dried at 98°C to remove excess water.

RESULTS

Sediment Stratigraphy

The sediment records of each of the four basins contained evidence for the early to mid-Holocene lowered water level previously observed in Core A of Walter's Puddle. The sediment stratigraphy varied slightly from basin to basin in terms of the composition and amount of material recovered. In each of the basins, between 28 and 70 cm of organic-rich mud overlay oxidized, inorganic clay, silt, and sand. A

TABLE 4

Radiocarbon Dates from Bay/ Basin Cores

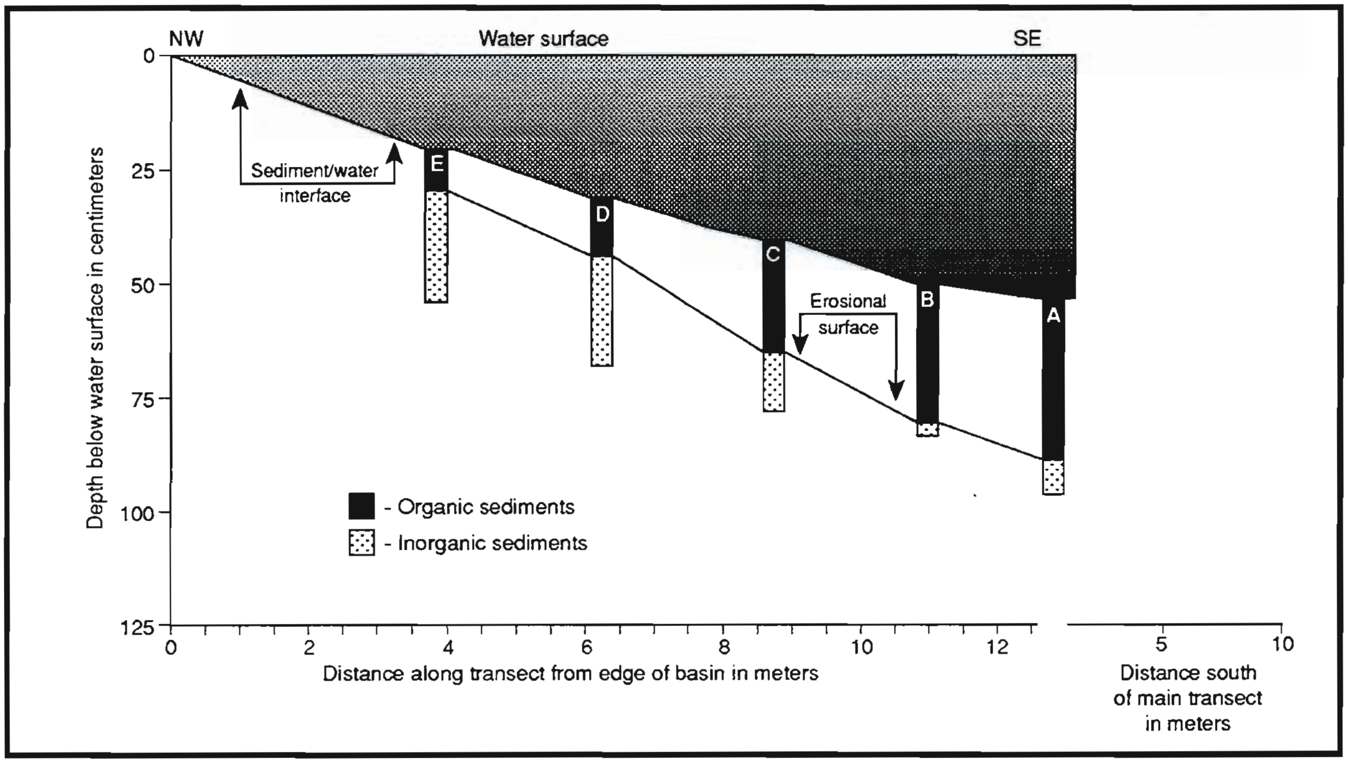
Site	Core	Depth (cm)	Date (BP)	Lab number
	B	30 - 35.5	3410 ± 80	WIS-2007
Longhauser	B	64 - 69	6190 ± 90	WIS-2008
Pond	B	71 - 78	10820 ±100	WIS-2009
	B	86 - 92	11610 ±100	WIS-2010
Nowakowski	A	57 - 59	6190 ±100	WIS-2007
Pond	A	64 - 67	10580 ±100	WIS-2008
Prison	A	24 - 26.5	2650±80	WIS-2022
Pond	A	34 - 41	11760 ±150	WIS-2023
	A	52 - 61	5820 ± 80	WIS-1802
Walters	A	63 - 69	11880 ±160	WIS-1803
Puddle	A	109 - 116	14400 ±150	WIS-1804
	B	25 - 30	2370 ± 80	WIS-2024

distinct hiatus with erosional features marked the transition from organic to inorganic-rich sediment in each of the cores. Color differences across the hiatus were observed with dark brown to black material above and yellow to blue/gray material below the hiatus.

Longhauser Pond. The sediment stratigraphies of the six cores from Longhauser Pond are summarized in Figure 27 and Appendix II. In each of the inner five cores, A-E, the upper most sediment unit was a fibrous peat ranging in thickness between less than 5 cm at Core C to 30 cm in Core B. The surface sediments of the outermost and shallowest core, F, were finer grain and more decomposed. Underlying the upper unit in each of the cores was a fine organic clay and silt unit, close to 30 cm thick with some macrofossils. The third sedimentary unit, a dark organic lake mud ranging in thickness between 10 and 15 cm directly overlay the hiatus. Clasts of material similar to that directly below the hiatus were present at the base of this unit along with occasional well-rounded pebbles. The hiatus separating the organic material above and inorganic material below was uneven and sharp. The sediments below the hiatus were a mixture of inorganic clays, silts, and sand. A thin coarse grain sand layer was present in Core A. The large diameter of Core B facilitated the identification of mud cracks in three dimensions. These mud cracks extended 10 to 15 cm below the hiatus from 70 to 85 cm and were filled by organic-rich material from above. Immediately below the hiatus in Core B the sediments was a dark, fine grain clay and silt. The depth of the hiatus followed the present basin morphometry (Figure 27) and is close to 30 cm deeper in the center of the basin. The loss-on-ignition data from these cores matched the sediment description with higher percent organic material above and lower percent organic below the hiatus (Appendix II).

FIGURE 29

Stratigraphic Profile of Prison Pond



Nowakowski Pond. The sediment stratigraphies of the nine cores from Nowakowski Pond are shown in Figures 28 and Appendix II. The upper-most sediments in each of the cores were fine-grained, decomposed organic silt between 3 (Core I) and 15 cm thick (Core B). Underlying the upper unit in each of the cores was a transition unit of fine organic clay and silt up to 35 cm thick with some macrofossils. Dark, organic lake mud ranging between 10 and 20 cm in thickness directly overlay the hiatus. As in Longhauser Pond, there were clasts of the underlying material at the base of this unit immediately above the hiatus. The hiatus was sharp, but uneven in most of the cores. The sediments below the hiatus were a mixture of inorganic clays, silts, and sand. Mud cracks, filled by organic-rich material from above, were also observed below the hiatus in the large diameter core, A. The depth of the hiatus followed the present basin morphometry in all the cores except in Cores C and D (Figure 28), and was 30 cm deeper in the center of the basin. The loss-on-ignition data from these cores also matched the sediment description with higher percent organic material above and lower percent organic below the hiatus (Appendix II).

Prison Pond. The sediment stratigraphies of the five cores from Prison Pond are summarized in Figures 29 and Appendix II. The upper-most sediments in each of the cores was an organic-rich silt. Directly underlying this organic-rich silt was a hiatus that separated the organic material above and inorganic clays, silts, and sand, below. The depth of the hiatus followed the present basin morphometry (Figure 29). The loss-on-ignition data from the cores did not consistently follow the sediment description of higher percent organic material above and lower percent organic below the hiatus (Appendix II).

Walter's Puddle. The sediment stratigraphies of the five cores from Walter's Puddle indicate that the upper most sediments in the three middle cores, B, C, and D, were a modern disturbance mishmash of sands and silts (Figure 30 and Appendix II). Core A, taken two years earlier, had was undisturbed, and

FIGURE 30

Stratigraphic Profile of Walter's Puddle

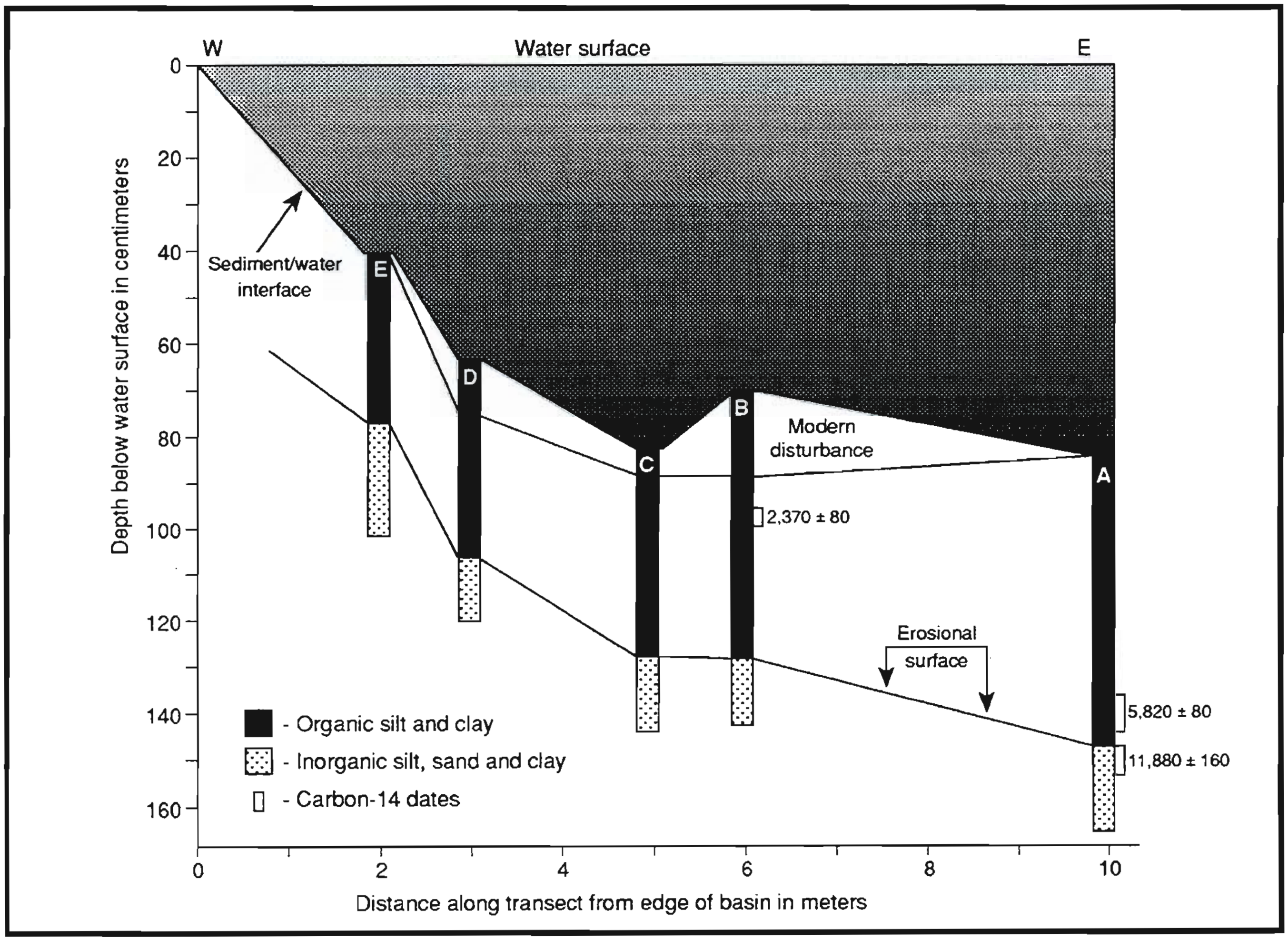
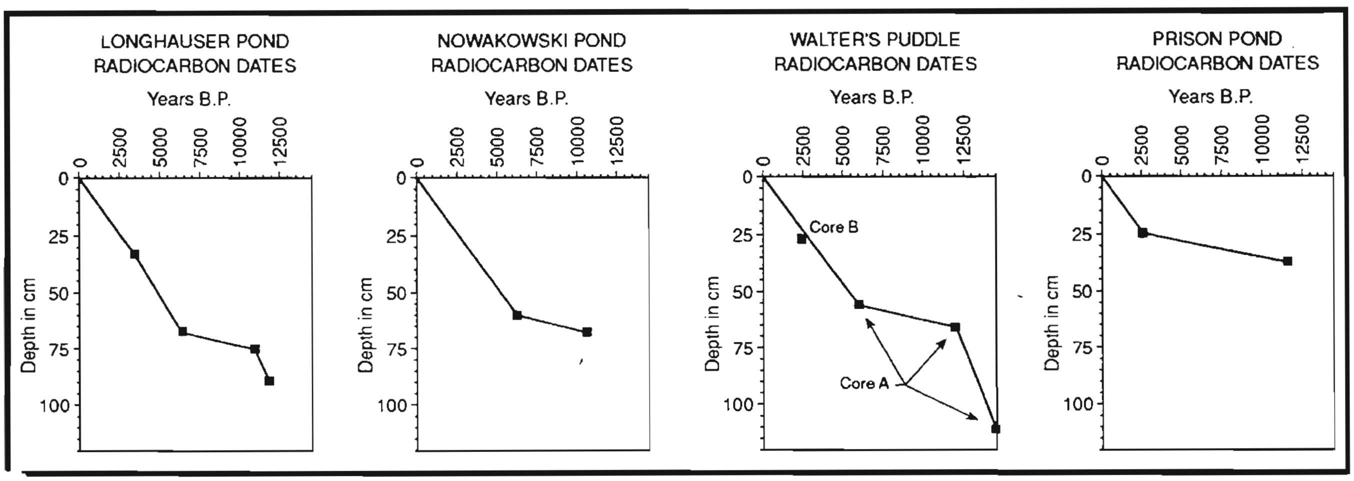


FIGURE 31

Age vs. Depth Plots for the Bay/Basin Cores



Core E was far enough removed to remain undisturbed. The surface sediments from Cores A and E were a coarse, detrital-rich, organic silt. Underlying the upper sediments of each of the cores was transition unit of fine organic clay and silt unit. Dark, organic lake mud, ranging between 10 and 15 cm in thickness, directly overlay the hiatus. Rip-up clasts were found immediately above the hiatus. The sediments below the hiatus were a mixture of inorganic silts and sand grading into a silty, inorganic clay. The depth of the hiatus (Figure 30) is consistently deeper going from the edge of the basin at Core E towards the center of the basin at Core B. Stratigraphic correlation of these cores to Core A can be made although they are complicated by the modern disturbance. We cannot yet say whether the hiatus in Core A was significantly deeper than in Core B or relate the present morphometry of the basin to the depth of the hiatus. The loss-on-ignition data from these cores also matched the sediment description with higher percent organic material above and lower percent organic below the hiatus (Appendix II).

Radiocarbon Dates

Bracketing radiocarbon dates from three of the basins, Longhauser Pond, Nowakowski Pond, and Walter's Puddle, consistently date the break in sediment accumulation within the basins to be from 11,000 to 6,000 BP (Table 4; Figure 31). Discrepancies in the dates from one basin to the next can be explained as a combination of:

1) differences in the deposition/erosion history at each of the basins; and

2) differences in the composition and sample size of the material dated.

The 3410 BP date at a depth of 33 cm from Longhauser Pond confirms that accumulation rates in the basin have remained fairly constant over the last 6,000 years (10 cm/10^3 yr). The basal dates from Longhauser Pond (11,610 BP) and Walter's Puddle (14,400 BP) suggest that sediment accumulated at a higher rate in the late glacial in these basins (20 cm/10^3 yr) than during the latter part of the Holocene (Table 4). Even the mid to late-Holocene and late-glacial rates of sediment accumulation in these basins are low compared with the rates of accumulation in most continuously wet basins during the Holocene. Webb and Webb (1988) show that rates below 10 to 15 cm/10^3 yr are frequently associated with discontinuous sediment accumulation processes.

DISCUSSION

Regional Stratigraphy

We have been able to develop a regional chronology for the area based upon the similar sedimentary records and consistent chronology observed at each of the four basins (Table 5). The appearance of a major stratigraphic break in each of the cores from the four basins demonstrates that the hiatus that had been observed at Walter's Puddle is not unique. The presence of this feature at Prison Pond, 15 km to the south and in a different drainage system suggests that this is a regional change in effective moisture rather then a local hydrologic event. The multiple core transects record the erosional surface as a continuous and uniform feature within each of the basins. The bracketing radiocarbon dates consistently estimate the period of depressed water level to be from 11,000 to 6,000 BP. Prior to 11,000 BP the water levels were high enough to allow sediment accumulation at rates of nearly 20 cm/1000 yr. Depressed temperatures and a reduced nutrient supply are possible explanations for the organic-poor nature of these sediments.

TABLE 5

Regional Lake Sediment Chronology Chart for Central Delaware

Regional History (years BP)	Sediment Accumulation Rate (cm/ 1000 yr) Longhauser Pond	Nowakowski Pond	Prison Pond	Walters Puddle	Walters Puddle Pollen Zone	Interpretation
	9.6					
3400		9.3	4.7*	9.6	Zone 1 Oak-Buttonbush	- accumulation of organic-rich detrital sediments in shallow intermittantly dry basins - gradual rise in water table to modern level
6000	12.5					
	1.6	1.7	2.1*	1.6		- haitus, erosional surface with sessication and sediment removal - water table close to 140 cm below modern level
11000	18.9			18.4	Zone 2 Spruce-Pine-Birch-Sedge	- water depths sufficient to permit the deposition and accumulation of inorganic clays, silts, and sands
14500						
>20000*					Zone 3 Spruce-Oak-Sedge	- inorganic sediment accumulation in low productivity, cold/ wet environment

* estimated

Between 11,000 and 6,000 BP, water levels dropped resulting in desiccation and deflation of previously deposited material as well as inhibiting the accumulation of any additional sediments. After 6000 BP, water levels rose sufficiently to permit the production and accumulation of organic-rich sediments.

The presence of rip-up clasts at Longhauser Pond, and mud cracks at Nowakowski Pond, and Walter's Puddle confirm that the hiatus is an erosional feature in each of the basins. The mud cracks extend the minimum depth of the water level drop below the depth of the hiatus. Water levels dropped at least 10 to 15 cm below the depth of the hiatus in Cores A and B at Nowakowski Pond and Longhauser Pond, respectively. The minimum estimates for the late-glacial to mid-Holocene drop in water level ranges from as little as 83 cm at Prison Pond to 147 cm at Walter's Puddle. The drops in water levels at Longhauser and Nowakowski Ponds are estimated to be 91 and 125 cm, respectively. Maximum seasonal fluctuations in the water table elevation of central Delaware between 1950 and 1960 approach plus-or-minus 50 cm relative to the long term average elevation (Boggess and Adams 1964). The estimated magnitudes of water level lowering during the early Holocene in each of the basins investigated exceed this range of observed values and suggest that the hydrologic conditions were significantly different from those today. Modeling of the present and the paleohydrologic budgets of these basins should provide insight into the climatic conditions that would have caused such a water table lowering.

Archaeological Implications

The existence of a consistently dated hiatus (ca. 11,000 to 6000 BP) in sediment records of each of the four basins provides information that can be used to interpret regional changes in the prehistoric human settlement patterns in central Delaware during the Holocene. The period of most intensive use of this type of basin in central Delaware occurred between 4500 and 1900 BP. Archaeological evidence for activity around these basins prior to 4500 and after 1900 BP is not as well documented (Custer and Bachman 1986b). Archaeological investigations in New Jersey by Bonfiglio and Cresson (1981) suggest that this type of basin was actively used by humans during the early to mid-Holocene. The use of these basins by prehistoric groups may be related to sustained water levels within the basins and the resources available around them. Our data indicate that at least some of the basins were dry for some period between 11,000 and 6000 BP. The timing of this event may be at least a partial explanation for the absence of Paleo-Indian archaeological sites near the basins in central Delaware during the early Holocene. The regional increase in effective moisture, as suggested by our data, could provide an explanation for the observed evidence for greater human activity around and use of the basins after 6000 BP. If activity around, and use of the basins is shown to be related to 'wet' periods, additional analysis will be needed to explain the decline in archaeological sites near the basins after 1900 BP. Nevertheless, preliminary results suggest a correlation between regional changes in water levels of these basins and the timing and intensity of human activity in and around the basins.

SUMMARY

The stratigraphic records from four basins in Central Delaware contain evidence for a regional drop in water levels starting at the end of the late Pleistocene and extending into the early to mid-Holocene. Water levels appear to have been as low as 140 cm below the modern levels in the basins at some time between 11,000 and 6000 BP. Correlation of this event with the timing and intensity of human activity in and around this type of basin suggests that the observed patterns of human settlement in central Delaware during the early to mid-Holocene may be in response to changes in the effective moisture of the region.

THE HOLOCENE STRATIGRAPHY OF THREE FRESHWATER TO BRACKISH WETLANDS, KENT COUNTY, DELAWARE*

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INTRODUCTION

Objectives

The Holocene history of three tidal, freshwater to oligohaline (brackish) wetlands is examined in cores obtained from modern tidal channels and the adjacent valleys in order to:

1) describe the sediments deposited in modern Riverine, Estuarine, and Palustrine Wetland Systems;

2) describe the sediments deposited in the following wetland subenvironments (wetland classes): channel (Unconsolidated Bottom classes), unvegetated mud-flat (Flat and Emergent classes), and vegetated marsh (Emergent and Forested classes);

3) calculate and compare the sediment accumulation rates of the deposits from the sampled subenvironments: channel, unvegetated mudflat, and vegetated marsh;

4) relate the horizontal distribution and vertical sequence of sedimentary facies to the sea level rise of the Holocene transgression;

5) determine the Holocene history of the three wetland localities sampled by integrating the data from Objectives 1 through 4; and

6) integrate the specific geologic histories of the three localities into a generalized model of transgressive wetlands evolution.

These objectives are met by using modern analogs for past environments. Modern wetland environments are investigated. Then the results are used to interpret the buried wetland environments sampled by cores. The study provides a basis for interpreting the cultural activities, land use, and settlement patterns of prehistoric people whose campsites and villages have been found adjacent to the wetlands.

* This section combines Whallon's 1989 M.S. thesis in Geology at the University of Delaware with a paper published by Pizutto and (Whallon) Rogers (1992) in the Journal of Coastal Research.
The two documents were edited together by Douglas Kellogg.

Location and Geologic Setting of the Study Area

The three places under study are located 8 to 16 km inland (west to southwest) of Delaware Bay in the Atlantic Coastal Plain and Continental Shelf Geological Province (Kraft 1976). The area is underlain by a seaward-thickening wedge of Cenozoic and Mesozoic sediments (up to 2500 m thick near the Delaware shore), and blanketed by Pleistocene sands and gravels of the Columbia Formation (Kraft 1976; Pickett 1976).

Three localities were selected along the corridor of the proposed State Route 1 corridor, all within 1.5 km of the present Delaware State Highway 13 (Figure 2). The localities are in the Smyrna River, the St. Jones River, and the Leipsic River in Kent County, Delaware. These locations were selected because of their proximity to areas of intensive prehistoric settlement (Custer, Bachman, and Grettler 1986, 1987; Bachman, Grettler, and Custer 1988).

Modern Wetland Environments. Today, tidal stream valleys near the coast are occupied by salt-tolerant (halophytic) wetland species (for example, Spartina sp.) which form broad expanses of Estuarine Emergent salt marsh on the substrate of Holocene mud. Upstream, saline Estuarine waters become diluted by fresh water, forming brackish tidal streams and wetlands. Further inland, brackish wetlands are gradually replaced by tidal freshwater Riverine, or Palustrine environments. Beyond the limit of tidal influence are freshwater fluvial streams and wetlands.

The study areas are located in freshwater wetlands of the tidal stream channels and valleys above the influence of salt water. The dynamic transition between salt and fresh water has been characterized by Odum et al. (1984) as having:

1) near freshwater conditions (average annual salinity of 0.5 part per thousand or less);

2) plant and animal communities dominated by freshwater species; and

3) a daily, lunar tidal fluctuation.

The absence of saltwater stress combined with the nutrient fluxes of daily tides create a highly productive and diverse plant community with as many as 50 to 60 species at a single location (Odum et al. 1984).

Because of the difficulties of surveying in these wetland environments the elevations of the coring localities were not determined directly. However, large scale maps (1:600) with a contour interval of 30 cm (1 ft.) and spot elevations accurate to 3 cm (0.1 ft.) cover the coring locations. Wetland surfaces on the maps range from 0.30 to 0.90 m above mean sea level (National Geodetic Vertical Datum of 1929). The mean semidiurnal tidal range is 1.07 m at the closest tide gauge about five miles downstream (east) of the Leipsic River core locality (National Oceanic and Atmospheric Administration 1988).

Wetlands

The term 'wetland' describes a variety of environments characterized by low relief and frequently saturated soil (Cowardin et al. 1979). Marshes, swamps, bogs, and flooded bottomland forests are all wetland environments. Wetlands typically occupy the region between permanently flooded habitats (lakes, rivers, and coastal embayments) and rarely flooded uplands. Wetlands are defined by the Fish and Wildlife Service (Cowardin et al. 1979) as:

"... lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes:

1) at least periodically, the land supports predominantly hydrophytes;

2) the substrate is predominantly undrained hydric soil; and

3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year."

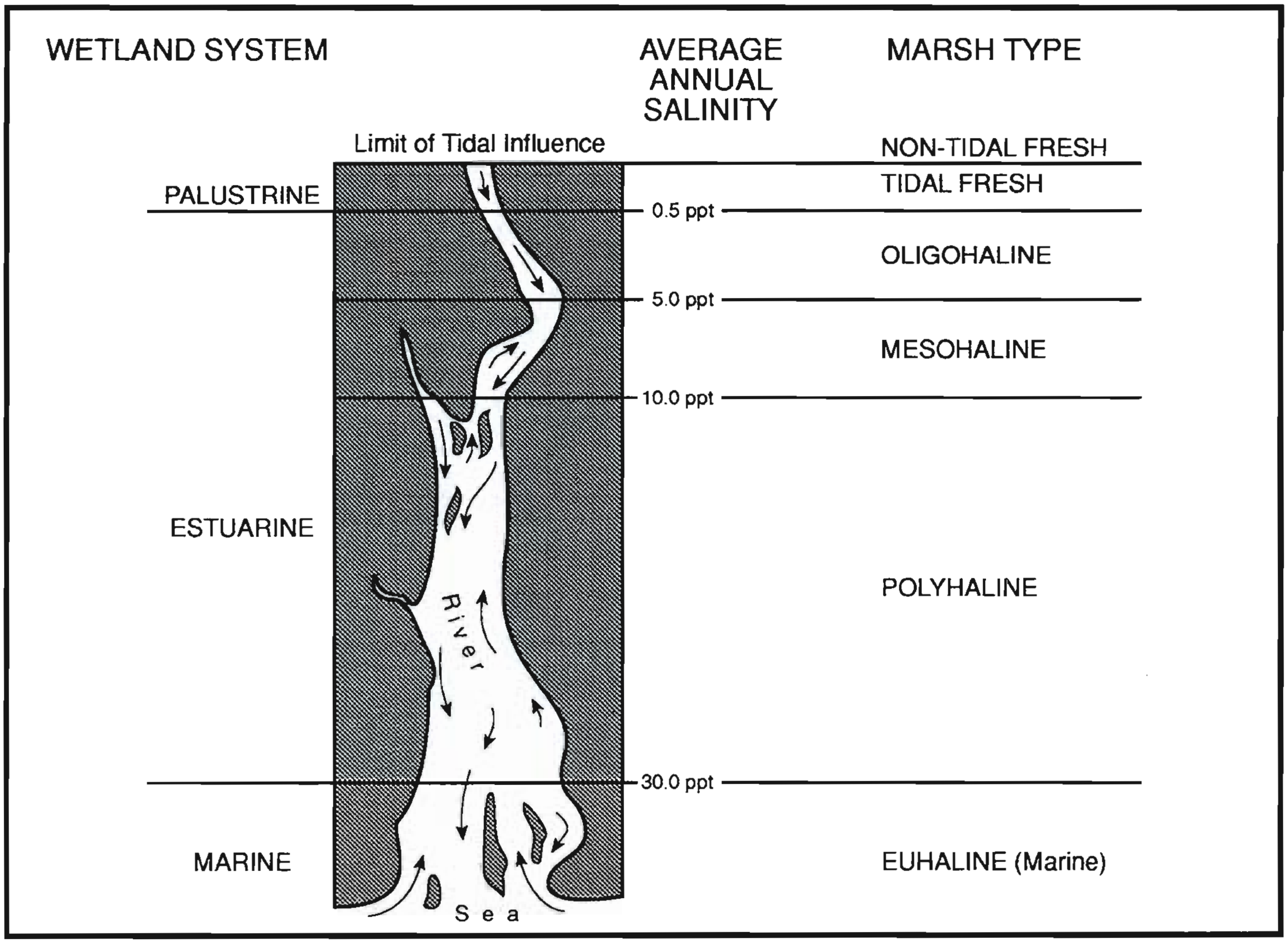
This definition recognizes the contributions of hydrology, vegetation, and soil type, and integrates the three aspects of wetlands into one coherent statement.

Cowardin et al. (1979) classified wetland environments according to hydrologic, geomorphic, chemical, or biological factors. The structure of the classification system is hierarchal, from general to specific. At the most general level, a wetland is defined as belonging to one of five 'systems': Marine, Estuarine, Lacustrine, Riverine, or Palustrine (Figure 32). Each system except for the Palustrine is further subdivided into 'subsystems' based upon water characteristics (for example, tidal, intermittent, etc.). Subsystems are divided into 'classes' described either by the dominant type of hydrophytic vegetation (for example, emergent, forested, etc.) or, if vegetable cover is less than 30%, by composition of the substrate (for example, rocky shore). Details of the vegetation (for example, broad-leaf deciduous) or the sediment size of the substrate (for example, sand, mud, etc.) are given by the 'subclass' grouping. Conditions of soil saturation or flooding are described by water regime modifiers for both tidal (for example, regularly flooded, irregularly exposed, etc.) and non-tidal (for example, intermittent, seasonally flooded, etc.) wetlands. Water chemistry modifiers describe the hydrogen ion concentration (pH) and salinity of the water.

Most research on wetlands has focused on Estuarine Emergent wetlands known as coastal salt marshes (see references cited in Frey and Basan 1985). More than a century of detailed investigations have produced voluminous literature on the origin and development of salt marshes (Mudge 1862; Shaler 1886; Chapman 1938), including the significance of salt marsh deposits as indications of sea level change caused by Pleistocene glaciations (see Bloom 1964; Redfield 1972; Kraft 1971; Rampino and Sanders 1981).

Freshwater wetlands of the Palustrine, Riverine, and Lacustrine systems have received little attention from geologists. Most investigations describe modern ecosystem processes such as primary production, energy flux, and nutrient exchange (for example, Good, Whigham, and Simpson 1978; Odum et al. 1984). Such descriptions lack a genetic or evolutionary perspective and do not provide a basis for interpreting wetland environments of the past as represented by sedimentary deposits. Wetland ecosystem development by plant succession has been addressed (for example, Mitsch and Gosselink 1986), but again the time scale is too short for geologic purposes. As a result, the evolution of freshwater wetlands as sedimentary environments is poorly understood.

FIGURE 32
Relationship Between Wetlands and Salinity



METHODS

Field Methods

Twenty-seven vibracores, six piston cores, and 16 Eijkelkamp 2.5 cm diameter hand driven cores were obtained during the summers of 1987 and 1988. Vibracores (Plate 4) were collected following the procedures of Hoyt and Demarest (1981). Vibracores were cut into halves lengthwise in the laboratory. One half was cut into 1 m sections, photographed, and then stored. The other half of each core was described and sampled for laboratory analysis.

Methods for Determining Lithologies

The lithology of sedimentary units within the cores was determined primarily by a visual inspection. Sediments were first classified as either mineral (sand or mud) or organic (peat) on the basis of their estimated organic content (U.S. Soil Conservation Service 1975). The size of sand grains (coarse, medium,

PLATE 4

Vibracoring a Wetland Study Locality

A section of aluminum irrigation pipe is vibrated into the mud and peat using a concrete vibrator attached to the pipe by a cable. The weight of the crew helps to force the corer into the mud. The core pipe is removed from the mud using a winch attached to the tripod.

and fine) were estimated by a visual comparison to a grain size diagram (Figure 12-1 in Compton 1962). In cases where the grain sizes or percent organic fraction of the sediment was uncertain, laboratory analyses were performed.

Laboratory Analyses

Grain Size Analysis. Sediments were soaked in a solution of 20% hydrogen peroxide and water for at least one week in order to dissolve the organic constituents. Then the solution was filtered through a 4 phi sieve using standard wet-sieve methods (Lewis 1984). After drying, the sand and mud fractions were weighed. Results are given in Appendix III.

Analysis of the Organic Content of Sediments. The organic content of samples was determined by Loss-On-Ignition (LOI) (Ball 1964). At least one sample was obtained from each lithologic unit in each core at intervals averaging from ten to thirty centimeters. Samples were dried overnight at 100°C, then weighed. Ignition at 375°C for 12 to 16 hours followed. Samples were then weighed again. The difference between the dry and ignited weights represents the amount of organic material in the sediments lost (burnt off) by the ignition process. Nearly 300 samples were analyzed (Appendix IV).

Based on the organic content of the sediment a lithologic could be assigned. Organic soils have been defined by the U.S. Soil Conservation Service (1975) as:

> "... saturated with water for long periods of time and (a) have an organic content of 18% or more if the mineral fraction is 60% or more clay, (b) have an organic content of 12% or more if the mineral fraction has no clay, or (c) have an organic content of between 12% and 18% if the mineral fraction has 0 to 60% clay."

The sediments of the study area consist of mixtures of gravel, sand, mud, and organic matter. The classification scheme in this study combined Folk (1974) for mineral sediments the with the U.S. Soil Conservation Service (1975) classification for organic-rich sediments. Sediments with organic content greater that 18% are termed "peat", a broader definition of peat than for "true peat" (for example, Kosters 1989). Ball (1964) suggested that LOI values inflate the percent organic carbon by as much as 100%; therefore, the cut-off between mineral sediments and peat was placed at 35% LOI in our classification scheme.

'Peat' is the term most frequently used to describe the organic deposits formed in temperate zone marsh environments (Allen 1974), although few such deposits have organic contents high enough to meet the requirements stated in the formal definition of peat. The Glossary of the American Geological Institute (Bates and Jackson 1987) defines peat as:

> "an unconsolidated deposit of semi-carbonized plant remains of a water saturated environment, such as a bog or fen, and of persistently high moisture content (at least 75%). It is considered an early stage or rank in the development of coal; carbon content is about 60% and oxygen content is about 30% (moisture free). Structures of the vegetal matter can be seen. When dried, peat burns freely."

FIGURE 33

Characteristic Loss-on-Ignition Curves for Different Types of Environments

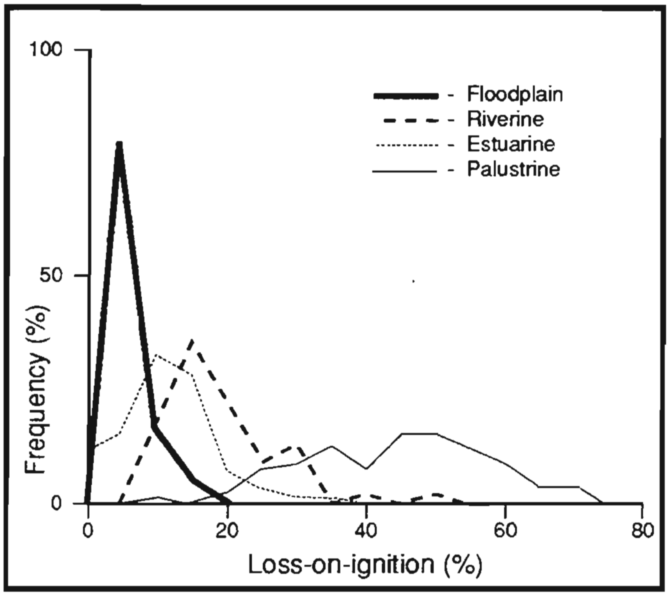


TABLE 6

Radiocarbon Dates for Wetland Cores

Core	Depth	Raw Date	Calibrated Age*
DC-1	205 cm	11,480±150	---
DC-3	120 cm 185 cm 205 cm	1370±110 5750±60 5620±70	1293 BP 6613, 6587, 6550 BP 6414 BP
SJ-1	300 cm	1890±220	1837 BP
SJ-3	80 cm 160 cm 338 cm	1040±220 1360±100 1920±70	951 BP 1290 BP
SJ-6	335 cm	3460±80	3800, 3799, 3710 BP
LR-1	175 cm	6230±270	7179 BP
LR-4	154 cm	3515 85	3831 BP
LR-5	216 cm	8020 100	8988 BP

* Using computer program CALIB (Stuiver and Reimer 1986).

Since few marsh deposits contain 60% organic carbon, a more general definition is preferred. Marsh peat, as defined by Redfield (1972), consists of:

> "material formed by mineral sediment deposited among vegetation and containing the roots and other parts of the plants either living or dead."

This qualitative definition is supplemented in this study by the application of the percentage of organic material required to produce an organic soil (U.S. Soil Conservation Service 1975). Peat thus defined includes abundant mud, and is frequently termed "muddy peat".

Supplemental Analyses. One half of one selected core from each of the study locality was sent to Grace Brush at The Johns Hopkins University for pollen analysis (see Brush in this volume). Selected peat samples were also sent to the University of Wisconsin Dating Lab for radiocarbon analysis (Table 6).

Determining Paleoenvironments

Observation alone did not provide a basis for distinguishing wetland environments within the cores because the lithologies are not unique and also because diagnostic sedimentary structures are not present. However, LOI values for sediment samples from modern environments cluster into three distinct groups (Figure 33). Sediments from floodplains have the lowest LOI values, while LOI values increase for riverine, estuarine, and palustrine wetlands. Whigham and Simpson (1976) and Jones and Cameron (1988) have used LOI to discriminate low from high salt marsh. Therefore, LOI was seen as a possible tool for discriminating past wetland environments.

Cross-sections were constructed for each area by correlating the lithologic logs of the cores. The lithologic units comprising each core had been previously identified as either sand (coarse, medium, or fine), peat (generally muddy), mud, or Low-organic mud. Adjacent equivalent lithologic units were correlated from core to core on the basis of lithologic similarity, both of grain size and organic content. The LOI values for each laterally equivalent lithologic unit were then compiled into one population. The subsurface populations were then statistically compared by Analysis of Variance to the LOI populations for modern wetland systems and classes.

RESULTS

The Duck Creek Locality

Six cores were obtained from Duck Creek (Figure 34 and Plate 5). The line of cross-section bisects the stream valley between cores DC-1 and DC-6, then parallels the channel from DC-6 through DC-4.

Description of Lithologies. The core log of DC-1 is representative of the lithologies of the Duck Creek area (Figure 35). Four distinct lithologic units are recognized:

1) a dark yellowish brown mud 71 cm deep containing organic fibers and large wood fragments with a highly organic (peaty) modern root zone (15-20 cm);

2) a grayish black, muddy peat with irregular lenses of fine sand and a large wood fragment;

PLATE 5

Aerial Photograph of the Duck Creek Study Locality

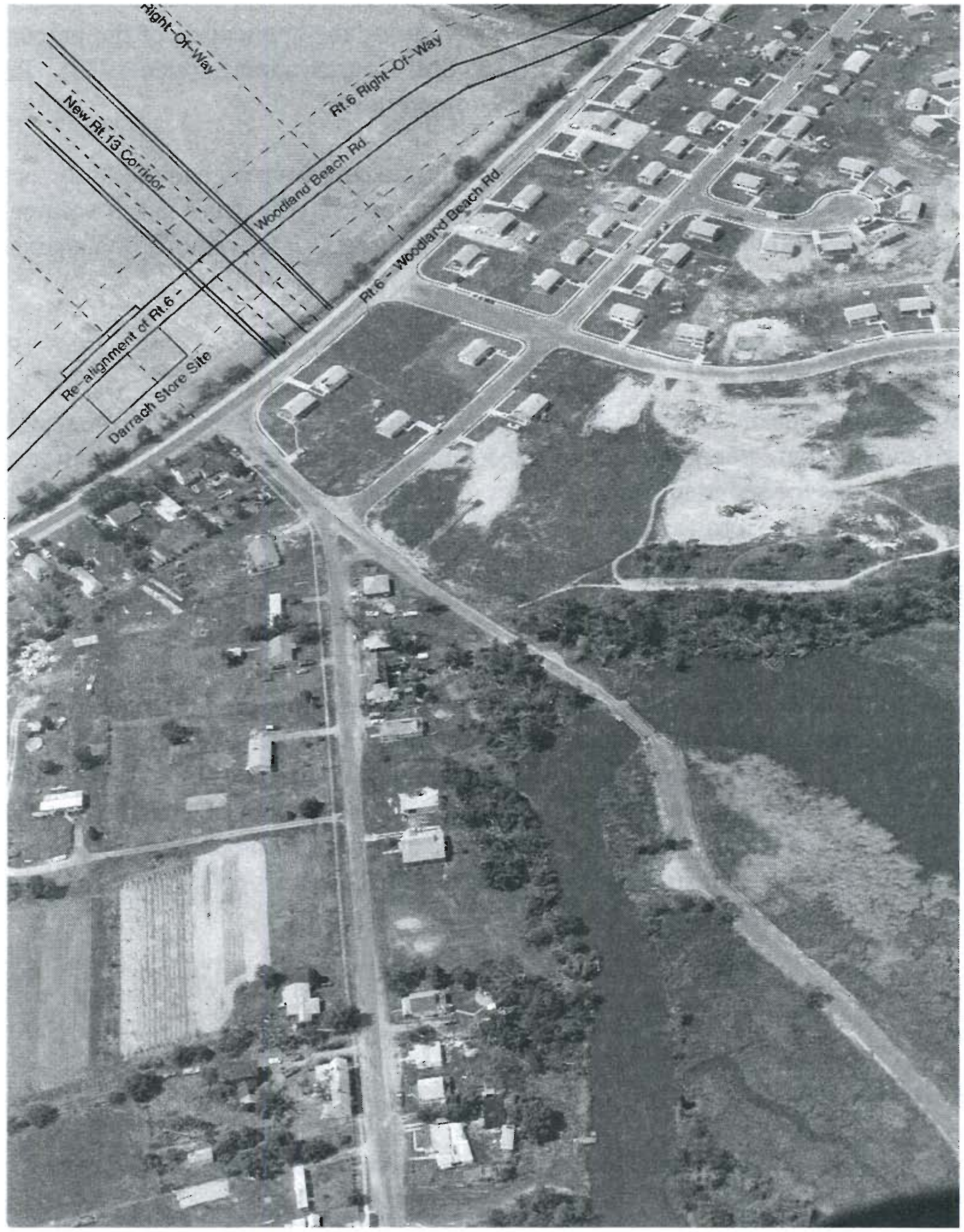


FIGURE 34

Duck Creek Study Locality

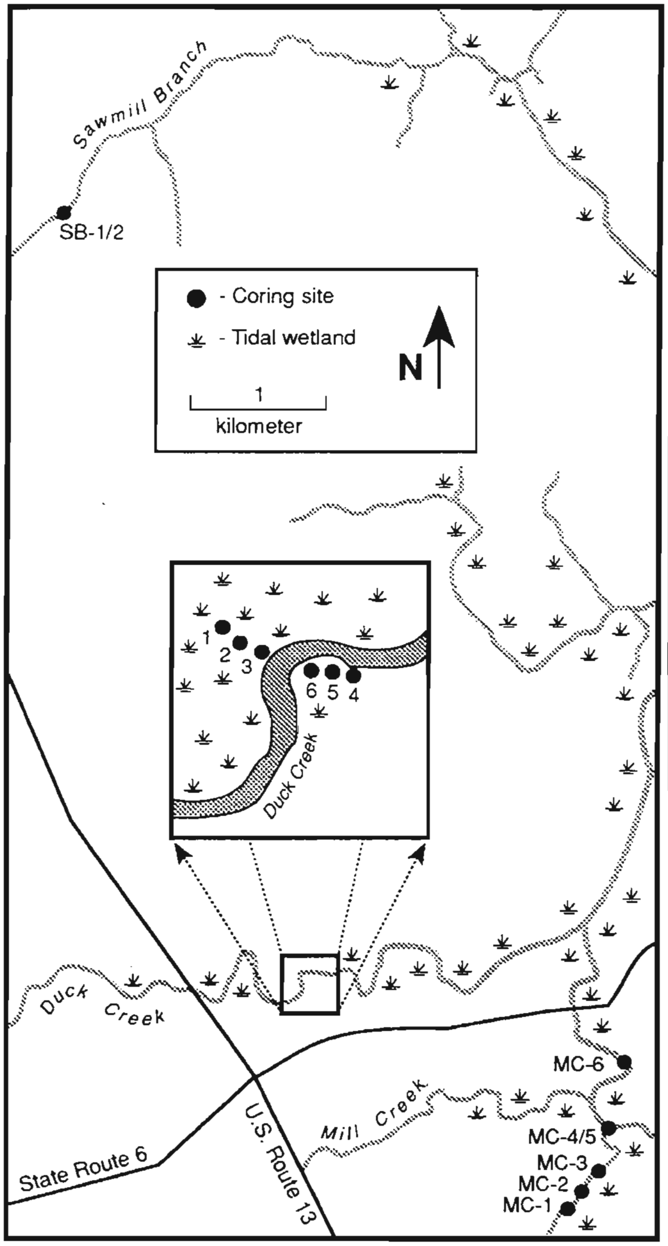


FIGURE 35

Representative Core from Duck Creek

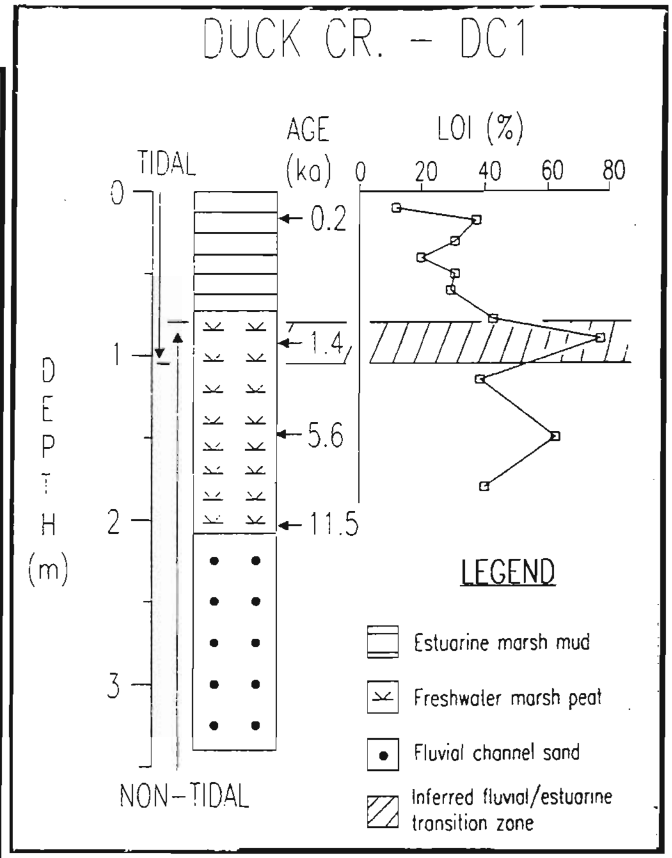
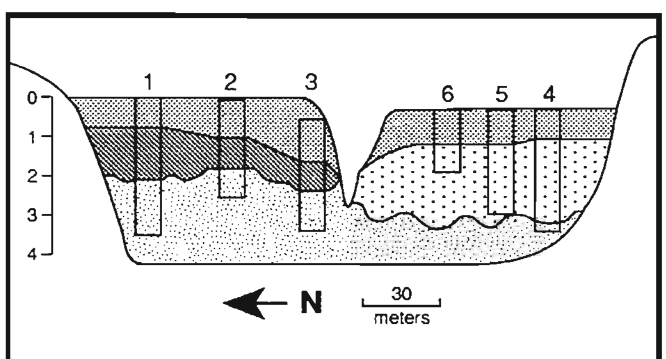


FIGURE 36

Stratigraphic Cross-Section of Duck Creek



	LITHOLOGY	WETLAND CLASS	ENVIRONMENT
	Mud	Estuarine	Brackish marsh
	Mud	Riverine	Tidal channel
	Peat	Palustrine	Freshwater marsh
	Sand	Riverine	Fluvial channel

3) fine to very fine sand, mostly massive but laminated with coarser sand near its base (306 cm); and

4) medium grained sand with irregular black laminae.

LOI values increase resulting in the gradational transition between units 1 and 2. The color shift to dusky yellowish brown at approximately 170 cm reflects a gradual increase in mud content relative to organic content (decreased LOI value). A radiocarbon age of 11,480 BP was reported for the base of unit 2 (205 cm).

Cross-Section. The cross-section (Figure 36) shows that approximately two meters of mud and peat overlie about one meter of either muddy sand near the center of the valley (cores DC-2 and DC-3), or clean sand along the valley margin (core DC-1). The clean sand is interpreted to be pre-Holocene in age, and is encountered only in this hole.

The Analyses of Variance (Table 7) indicate the following wetland environments for the lithologies, from oldest to youngest, of the Duck Creek study locality:

1) The clean sand at the base of core DC-1 was not analyzed as it is thought to represent the pre-Holocene 'basement' unit;

2) The muddy sand and sandy mud at the base of cores DC-2, DC-3, and DC-4 statistically correspond to a Riverine wetland environment;

3) The peat unit overlying the basal sandy units in cores DC-1, DC-2, and DC-3 corresponds to a Palustrine wetland environment;

4) The mud unit overlying the Palustrine peat unit in cores DC-2 and DC-3 could indicate either a Palustrine Emergent, Estuarine Emergent, Estuarine Flat, or Riverine wetland environment. It does not correspond to a Palustrine Forested environment;

5) The low-organic mud unit overlying the previous mud unit in cores DC-2 and DC-3 is anomalous. The same unit occurs at the base of cores DC-6, DC-5, and DC-4. The very low LOI values and massive nature of this unit have no modern analog in any of the modern environments sampled. This unit is statistically distinct from all modern populations; and

6) A peaty deposit labeled 'modern root zone' on Table 7 overlies the Low-organic mud in cores DC-3 and DC-6, and corresponds to a Palustrine wetland environment. Both the Emergent Peat and Emergent Mud correspond statistically to this unit, while Forested Mud does but Forested Peat does not correspond. The better correlation with the deposits of the Emergent class suggests an Emergent rather than a Forested class environment.

TABLE 7

Analysis of Variance Data for the Duck Creek Study Locality

Core Unit	Modern Environment	ANOVA Table	F (a = 0.05)	Populations distinct?	Environment
Peat	Total Riverine	125.00	4.09	Yes	PALUSTRINE (Emergent or Forested)
	Palustrine Emergent Peat	3.55	4.54	No	
	Palustrine Forested Peat	0.17	4.60	No	
	Total Palustrine Peat	0.74	4.28	No	
	Estuarine Flat	53.20	4.54	Yes	
	Estuarine Emergent	95.28	4.09	Yes	
	Total Estuarine	122.90	4.06	Yes	
Lower Organic Mud	Palustrine Emergent Mud	40.82	4.32	Yes	a ??? (Riverine?)
	Palustrine Forested Mud	266.99	4.35	Yes	
	Riverine Mud	20.36	4.32	Yes	
	Estuarine Flat	76.67	4.26	Yes	
	Estuarine Emergent	23.96	4.06	Yes	
Mud	Palustrine Emergent Mud	1.19	5.59	No	? Palustrine Emergent Riverine or Estuarine ?
	Palustrine Forested Mud	18.47	5.99	Yes	
	Riverine Mud	0.47	5.59	No	
	Estuarine Flat	0.08	4.96	No	
	Estuarine Emergent	0.03	4.16	No	
	Low Organic Mud*	76.43	4.41	Yes	
Muddy Sand	Riverine Sandy Mud	0.01	5.12	No	RIVERINE
	Riverine Sand	15.61	4.49	Yes	
Sandy Mud	Riverine Sandy Mud	0.23	4.84	No	RIVERINE
	Muddy Sand*	0.12	7.71	No	
Modern Root Zone	Palustrine Emergent Peat	1.15	4.84	No	PALUSTRINE (Emergent)
	Palustrine Forested Peat	10.79	4.96	Yes	
	Esturine Emergent	18.23	4.16	Yes	
	Total Estuarine	23.55	4.06	Yes	
	Palustrine Emergent Mud	3.83	5.23	No	
	Palustrine Forested Mud	1.31	5.59	No	
	Riverine Mud	19.98	5.32	Yes	
	Peat*	5.08	4.96	Yes	
	Mud*	9.77	6.61	Yes	

* Indicates comparisons to other subsurface units at this site.

The mud units comprising the tops of the cores are identified as Estuarine Flat (DC-3) and Emergent modern wetland environments (National Wetlands Inventory 1987 map of Smyrna, DE). The Low-organic mud lithology probably forms in a Riverine, Emergent, Non-persistent wetland environment. This modern environment was not sampled by any of the cores, since all of the core localities were mapped as having Persistant vegetation (National Wetlands Inventory 1987). Diagenesis by aerobic decomposition is the likely reason for the low organic content.

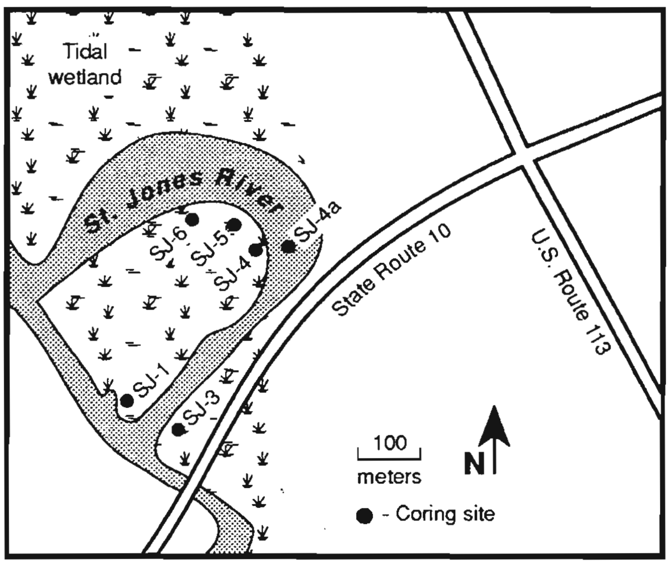
PLATE 6

Aerial Photograph of the St. Jones River Study Locality

The St. Jones River Locality

The locations of the six vibracores obtained at the St. Jones River locality (Plate 6) are shown on Figure 37. Eight Eijkelkamp cores were also taken, but not used in the cross-sections because the small core diameter precludes detail in the recovered sections and because no LOI analyses were performed. The Eijkelkamp cores were collected to provide additional information about the sediment type and the amount of compaction in the vibracores.

FIGURE 37
St. Jones River Study Locality



<u>Description</u> <u>of</u> <u>Lithologies</u>. Several lithologic units are identified in the representative core log (core SJ-6) for the St. Jones River area (Figure 38):

1) 43 cm of dusky-brown mud that grades into 2)

2) a compact dusky yellowish-brown mud (43-241cm) with low organic content (12%);

3) a sandy mud with pebbles from 241 to 292 cm, interbedded with lenses of medium grained sand;

4) dusky-brown organic mud from 292 to 334 cm radiocarbon dated to 3460±80 BP (330-334 cm); and

5) highly compacted sandy mud (334-351 cm) and fine sand (351-371 cm) speckled with vivianite, a cobalt-blue iron phosphate which forms in reduced environments in the absence of sulfur (P. Leavens, personal communication).

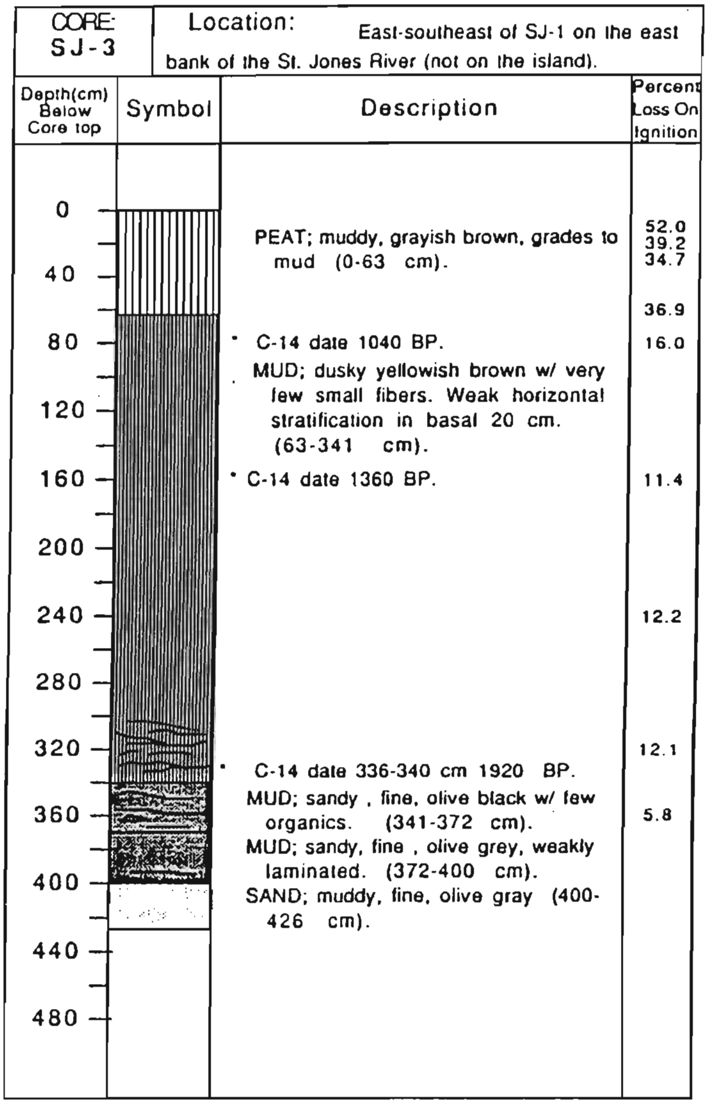
The six vibracores were used to construct two cross-sections (Figure 39). The cross-sections intersect different portions of the modern channel and abut against pre-Holocene outcrops along a valley wall. Deposits of peat and mud ranging from one to about four meters thick overlie more than two meters of sand and gravelly sand in core SJ-1 and overlie 20 cm of compacted fine sand and sandy mud in cores SJ-5 and SJ-6.

The results of the Analyses of Variance for the subsurface populations of the St. Jones River locality are shown in Table 8. The wetland environments determined for the units are listed below from oldest to youngest:

1) The basal sand and sandy mud units cannot distinguished from, and thus are identified as, Riverine wetland environment.

FIGURE 38

Representative Core from St. Jones River



2) A unit consisting of peat mixed with mud is sandwiched between Riverine muddy sand units near the base of SJ-6 ('SJ-6 Deep Mud' in Table 8). It corresponds to deposits of the Palustrine system, but it cannot be resolved at the class level (Emergent versus Forested).

3) A mud unit of low organic content ('Low-Organic mud') is found above the Riverine deposits in all of the cores except SJ-1. This unit is statistically distinct from all of the modern deposits, thus has no modern wetland environmental analog.

4) A peat unit overlies the Riverine deposit in SJ-1, and it corresponds to a Palustrine wetland system but cannot resolved to the class level.

5) Above the peat in SJ-1 and above the Low-organic mud in SJ-3, SJ-5, and SJ-6 is a mud unit of slightly greater organic content ('Mud 2'). This unit is statistically identified with both the Riverine and the Estuarine modern deposits. Since the sea level rise of Holocene

TABLE 8

Analysis of Variance Data for the St. Jones River Study Locality

Core Unit	Modern Environment	ANOVA Table	F (a= 0.05)	Populations distinct?	Enironment
Mud 1	Riverine Mud	16.60	5.12	Yes	PALUSTRINE (Emergent or Forested)
	Estuarine Flat	26.47	4.75	Yes	
	Estuarine Emergent	7.78	4.12	Yes	
	Palustrine Mud	0.12	4.60	No	
	Palustrine Emergent Mud	0.83	5.12	No	
	Palustrine Forested Mud	0.49	5.32	No	
	Mud 2*	37.78	4.75	Yes	
	SJ6 deep Mud*	1.18	5.99	No	
Mud 2	Riverine Mud	0.25	4.67	No	RIVERINE or ESTUARINE
	Estuarine Flat	0.29	4.49	No	
	Estuarine Emergent	0.57	4.09	No	
	Palustrine Mud	13.83	4.41	Yes	
	Palustrine Emergent Mud	15.19	5.59	Yes	
	Palustrine Forested Mud	25.28	4.96	Yes	
	Mud 1*	37.78	4.75	Yes	
	SJ6 deep Mud*	32.62	4.96	Yes	
Peat	Estuarine Emergent	88.29	4.04	Yes	PALUSTRINE (Emergent or Forested)
	Palustrine Emergent Peat	1.00	4.54	No	
	Palustrine Forested Peat	3.45	4.60	No	
Sandy Mud	Riverine Sandy Mud	4.07	4.45	No	RIVERINE
	Riverine Mud	11.63	4.60	Yes	
	Riverine Sand	18.60	4.26	Yes	
	Low Organic Mud*	16.77	4.23	Yes	
Low Organic Mud	Riverine Mud	6.00	4.30	Yes	??? (Riverine ?)
	Estuarine Flat	29.42	4.24	Yes	
	Estuarine Emergent	12.15	4.04	Yes	
	Palustrine Mud	56.66	4.17	Yes	
	Palustrine Emergent Mud	27.52	4.30	Yes	
	Palustrine Forested Mud	187.71	4.32	Yes	
SJ6 Deep Mud	Riverine Mud	15.19	5.59	Yes	PALUSTRINE (Emergent or Forested)
	Estuarine Flat	25.28	4.96	Yes	
	Estuarine Emergent	10.61	4.15	Yes	
	Palustrine Mud	1.51	4.75	No	
	Palustrine Emergent Mud	2.09	5.59	No	
	Palustrine Forested Mud	0.42	5.99	No	
	Peat*	5.20	5.12	Yes	

* Indicates comparisons between subsurface units at the same site.

time has not yet brought salt waters to this locality, the likelihood of Estuarine wetlands lying beneath the modern wetlands is very slight, so a Riverine environment is interpreted for this unit.

6) Overlying the Riverine mud unit in SJ-1, SJ-4, and SJ-5 is a peaty mud unit ('Mud 1') which cannot be distinguished from the Palustrine wetland system. The class level, Emergent or Forested, cannot be determined.

7) Overlying the Low Organic mud unit in SJ-4A is a sandy mud unit which represents a Riverine channel deposit.

The uppermost unit core SJ-4A is classified as Riverine Tidal Unconsolidated Bottom, and the remainder are Palustrine Emergent containing some randomly occurring Shrub Scrub areas (National Wetlands Inventory 1987 map of Dover, DE).

FIGURE 39

Stratigraphic Cross-Section of St. Jones River

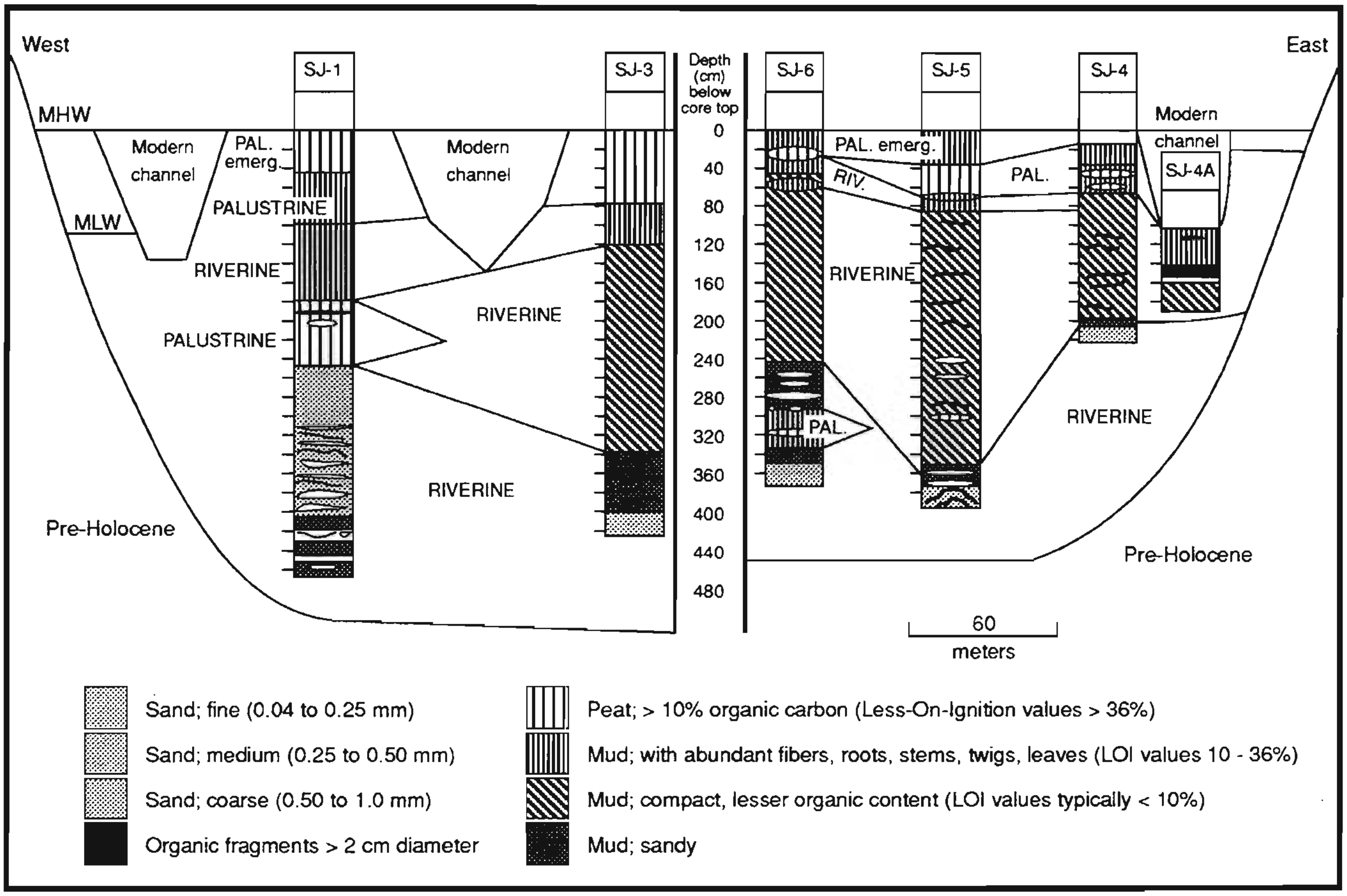
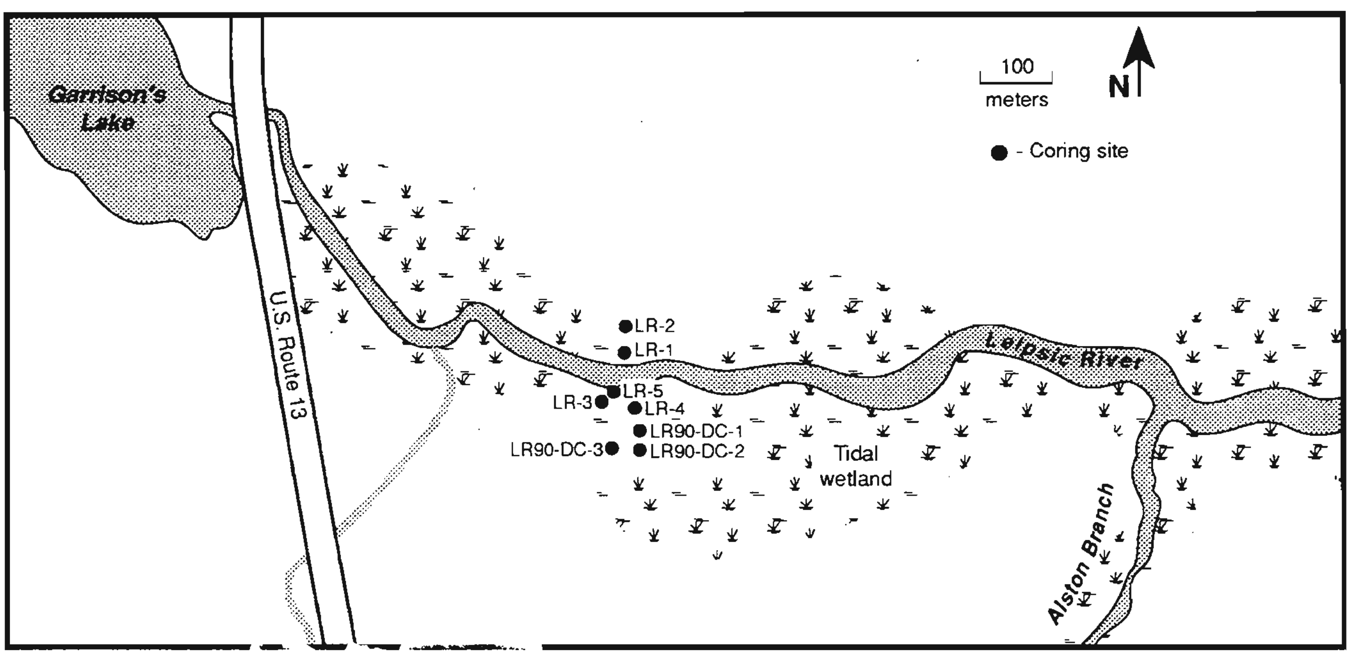


FIGURE 40

Leipsic River Study Locality



The Leipsic River Locality

Eight vibracores were obtained from the Leipsic River locality (Plate 7 and Figure 40). The line of cross-section bisects the tidal stream valley from core LR-2 to core LR-3.

Description of Lithologies. The representative core LR-90-DC3 (Figure 41) shows a vertical section consisting almost entirely of mud and peat. A darker, sandy mud occurs from 3 cm to 7 cm, but the majority of the core is composed of dusky-brown mud with variable amounts of organics. Some very large wood fragments occupy the entire 3 inch diameter of the core from 115-129 cm and from 131-139 cm. A sample of black organic mud from the base of the unit (217-220 cm) yielded a radiocarbon date of 8020±80 BP.

The cross-section (Figure 42) shows the vertical lithologic record and the relationships between adjacent cores. Between 1.5 and 2.5 m of mud and peat overlie a sandy unit which is encountered in three of the cores.

PLATE 7

Aerial Photograph of the Leipsic River Study Locality

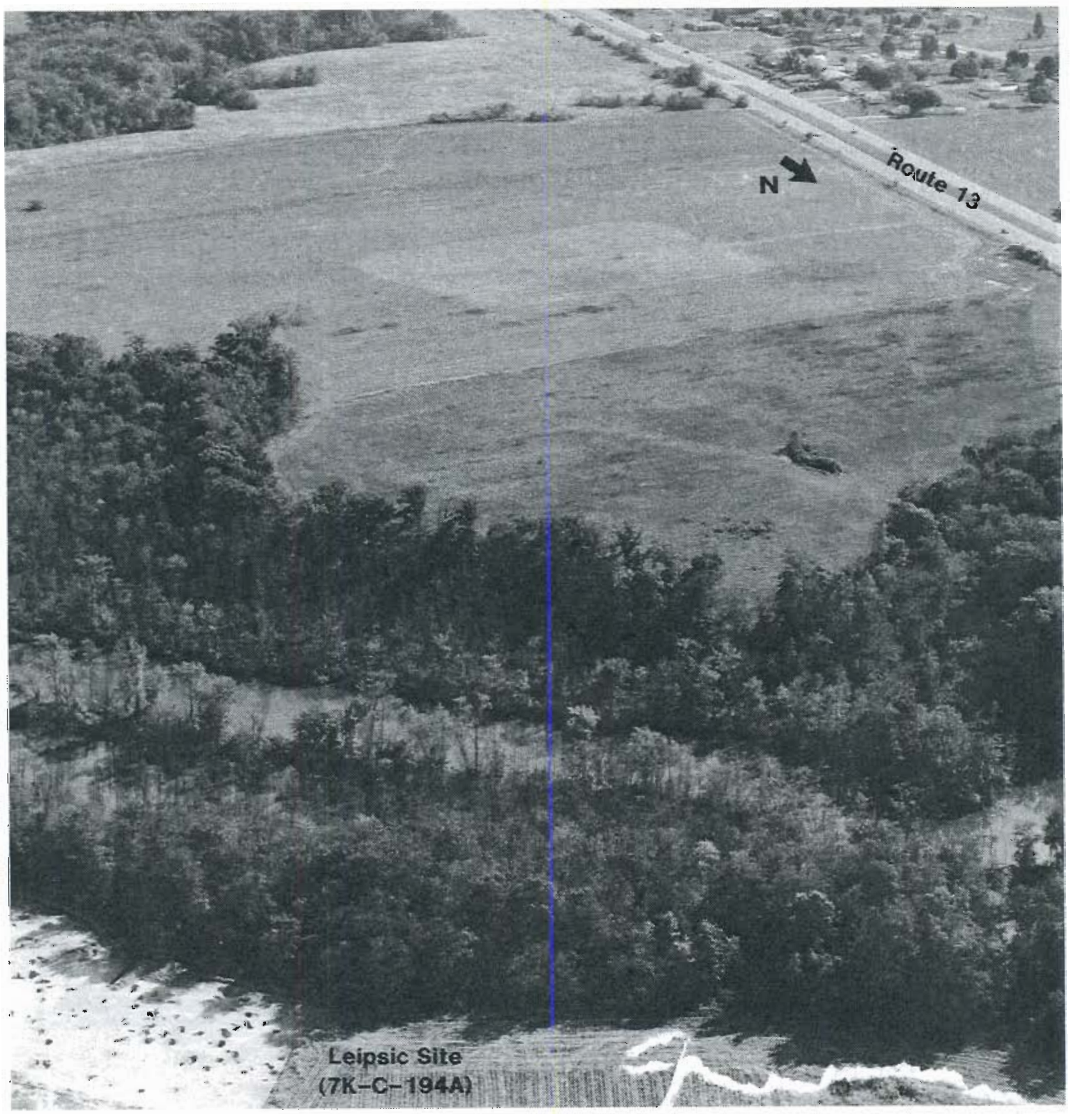


FIGURE 41

Representative Core from Leipsic River

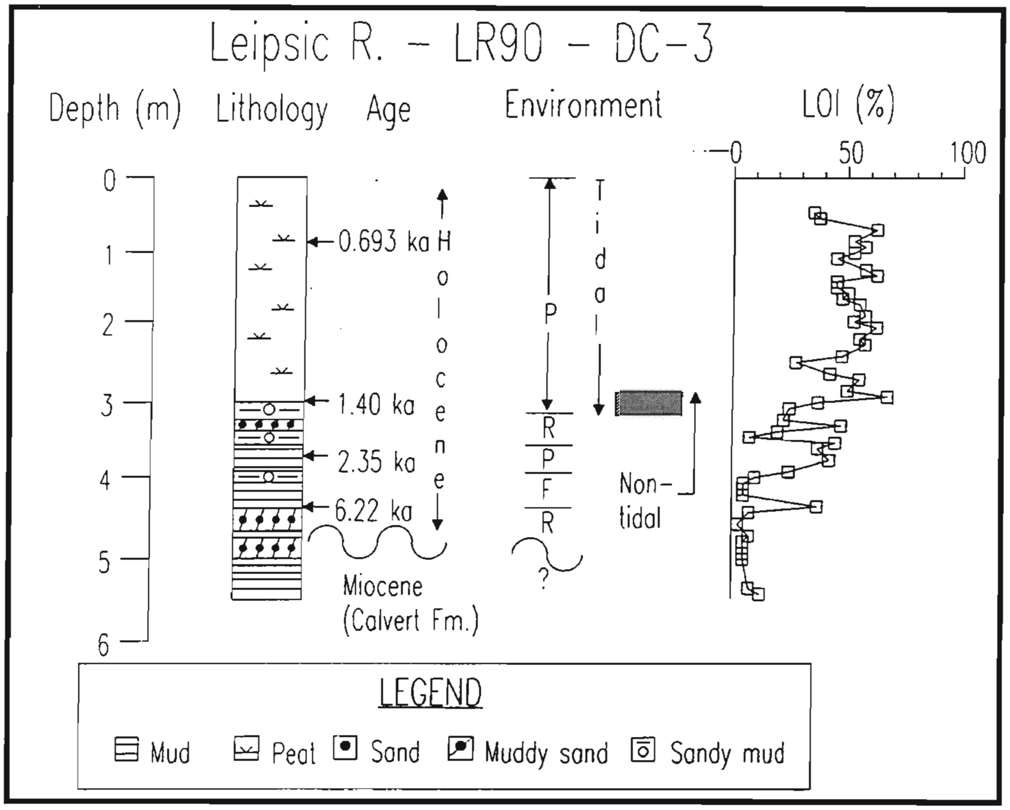


FIGURE 42

Stratigraphic Cross-Section of Leipsic River

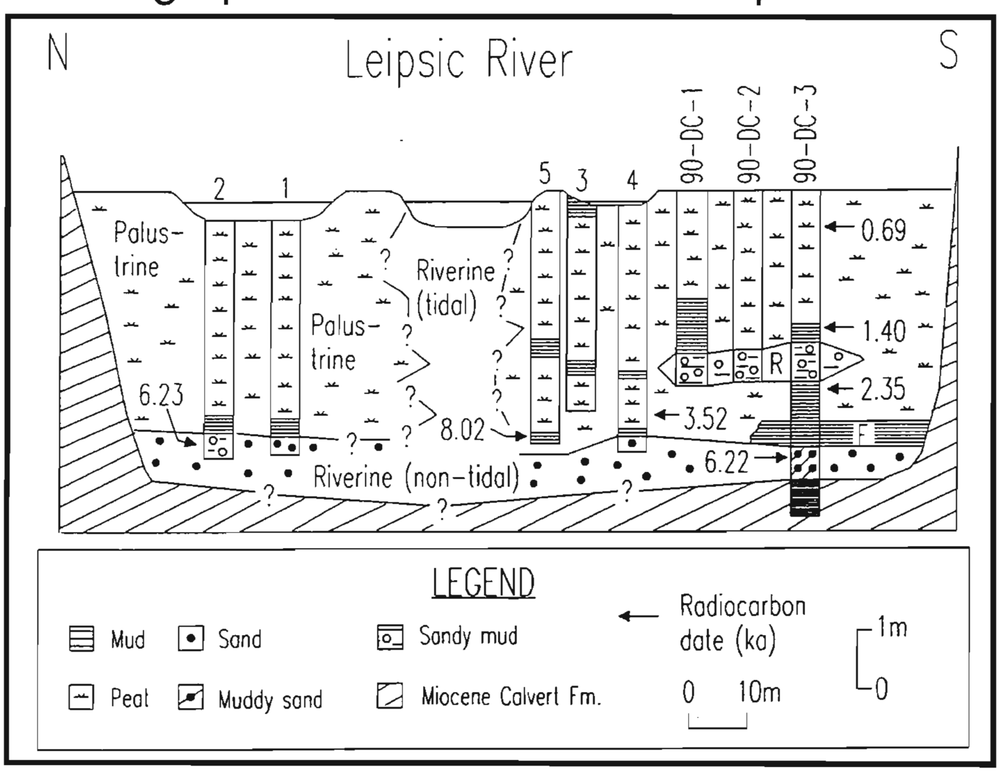


TABLE 9

Analysis of Variance Data for the Leipsic River Study Locality

Core Unit	Modern Environment	ANOVA Table	F (a=0.05)	Populations distinct?	Environment
Peat (high)	Palustrine Emergent Peat	8.81	4.32	Yes	PALUSTRINE Forested
	Palustrine Forested Peat	0.07	4.35	No	
Mud (high)	Palustrine Emergent Mud	0.06	4.84	No	PALUSTRINE (Emergent or Forested)
	Palustrine Forested Mud	2.16	4.96	No	
	Total Palustrine Mud	0.23	4.49	No	
	Total Estuarine	6.18	4.06	Yes	
Peat (low)	Palustrine Emergent Peat	0.69	4.60	No	PALUSTRINE Emergent
	Palustrine Forested Peat	5.40	4.67	Yes	
Mud (low)	Palustrine Emergent Mud	1.05	5.59	No	PALUSTRINE (Emergent or Forested)
	Palustrine Forested Mud	0.02	5.99	No	
	Total Palustrine Mud	0.38	4.75	No	
	Total Estuarine	8.69	4.08	Yes	
Sandy Mud	Riverine Sandy Mud	1.81	4.96	No	RIVERINE
	Riverine Mud	5.60	5.59	Yes(/)	

The results of ANOVA are shown in Table 9. The wetland environments for the populations from subsurface units, from oldest to youngest, are as follows:

1) compacted sand units in the base of LR-2 and LR-4 are probably Pre-Holocene;

2) sandy mud deposits near the base in cores LR-2, LR-1, and LR-5 correspond to a Riverine wetland system;

3) a mud unit overlying the pre-Holocene sand in core LR-4 and above the Riverine sandy mud in core LR-5 ('Mud low' on Table 9) indicates a Palustrine wetland, which cannot be further resolved to the class level;

4) above the mud unit in cores LR-4 and LR-5 and forming the basal deposit in core LR-3 is a peat unit ('Peat low') which corresponds statistically to an Emergent class Palustrine system wetland;

5) a unit of mud overlies the Palustrine peat unit in cores LR-3, LR-4, and LR-5, and overlies the Riverine sandy mud in LR-1 ('Mud high'). This mud corresponds to a Palustrine system of an unresolved class; and

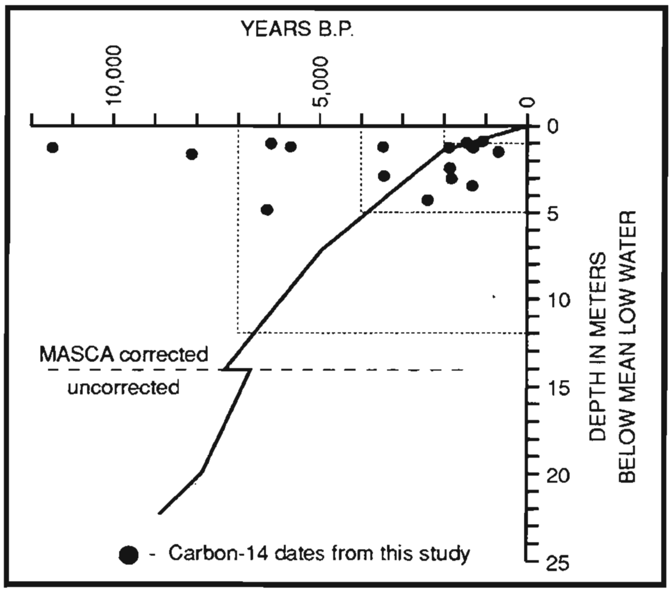
6) above the Riverine sandy mud in core LR-2 and above the Palustrine mud in the other cores is a peat unit ('Peat high') which corresponds statistically to Forested class Palustrine wetland.

The Palustrine Forested wetland environment at the top of the cores was determined by reference to National Wetlands Inventory (1987) map of Smyrna, DE.

FIGURE 43

Delaware Coast

Relative Sea Level Curve



(After Kraft 1976) Radiocarbon dates that plot above the sea level curve are from fresh water environments. Dates that plot below the sea level curve are from brackish or marine environments.

THE HOLOCENE EVOLUTION OF THE WETLANDS OF THE STUDY AREA

Determining the Time of Tidal Incursion

The depths of sedimentary units with respect to the marsh surface were known from their core positions. The time of tidal arrival in years before present for a given depth could be determined from Kraft's (1976) local relative sea-level curve (Figure 43). If the plot of the depth versus age for a given sedimentary deposit coincided with the line of the sea level curve, the unit was interpreted to have originated in a transgressive environment. For example, a marsh peat encountered at a depth of 3 m below mean low sea level with a radiocarbon date of 3000 BP would be considered to be a transgressive unit whose origin was related to the relative rise in sea level, while a peat unit from the same depth but dated at 6000 BP would not. Figure 43 shows that the relative rise in sea level inundated incised stream valleys to depths of approximately -12 m around 7000 BP, -5 m around 4000 BP, and -1 m around 2000 BP (Kraft 1976).

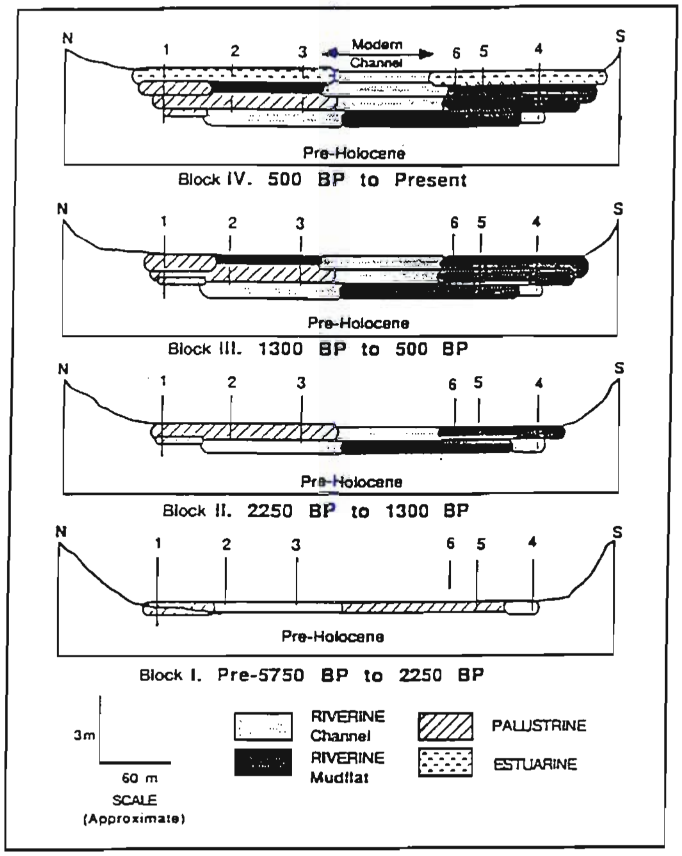
Age versus depth plots of the dated core horizons have been located on the relative sea-level curve (Figure 43). Deposits from cores SJ-1, SJ-3, TS-8, and the top unit from DC-3 are interpreted to be tidal in origin, while the remainder of the dated deposits predate the tidal transgression.

A few potential sources of error exist for this approach (Fletcher 1988). Sediment compaction and changes in tidal range may contribute to some measure of uncertainty in the sea level curve. However, the compaction of core sediments may represent the most significant source of error. Most of the dated deposits are not basal Holocene units and the highly organic nature of most marsh sediments renders them subject to significant compaction over time (Bloom 1964; Kaye and Barghoorn 1964). The apparent depths of the dated sediments in the cores might not be equivalent to the depths at which they were originally deposited.

The probability of this type of error was minimized by taking radiocarbon dates directly above sand deposits or Low-organic mud deposits which probably experienced little compaction relative to that of organic mud or peat. Other indicators of a transgressive environment were also used to supplement the relative sea level curve. An increase in the rate of inorganic sedimentation would indicate the addition of sediment from tidal sources. An increase in the percentage of mud may accompany this increase in sediment accumulation rate. The pollen record may also show an increase in 'wetter' species, both herbaceous and woody, as the local vegetation adjusted to an increase in the base water levels followed by periods of tidal inundation.

FIGURE 44

Development of Wetlands at Duck Creek



Sediment Accumulation Rates

Sediment accumulation rates were calculated for one core from each of the three localities constituting the study area. Average rates of sediment accumulation were calculated for each different lithology by dividing the sediment thickness by the elapsed time interval. Radiocarbon dates were obtained from specific horizons, and the time distribution between these dates was determined using variations in the pollen influxes (Brush 1989). The rates thus obtained allow comparisons of sediment accumulation in different wetland environments, and permit a more detailed chronological sequence of wetlands evolution to be constructed for each analyzed core.

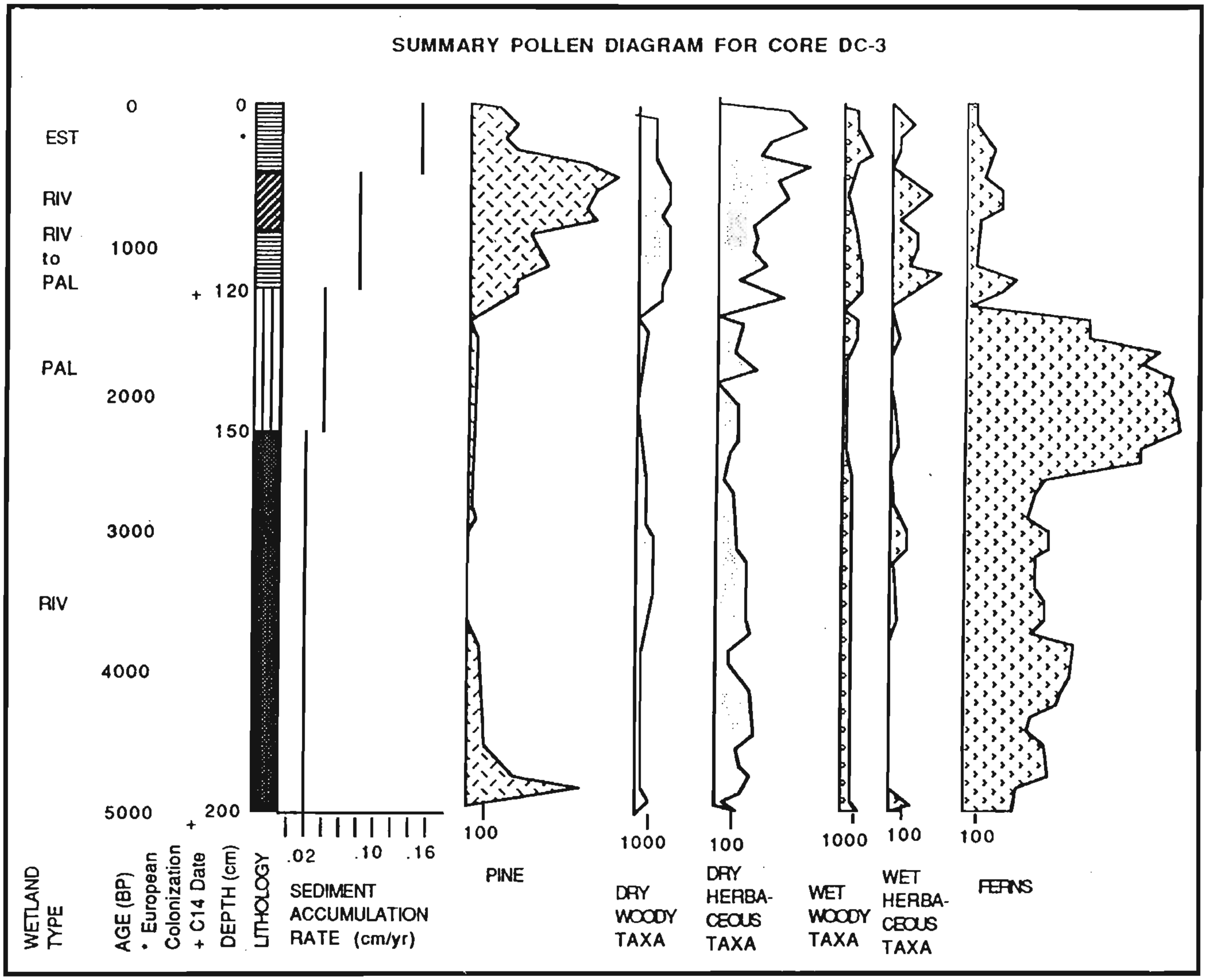
Duck Creek on the Smyrna River

The Holocene sequence of wetlands at the Duck Creek locality is presented below from the oldest known environment to the modern, and is illustrated by a schematic diagram (Figure 44). Refer to the cross-section for scaled lateral and vertical relationships (Figure 36) and Appendix V for lithologic detail from individual core logs. Analyses of core DC-3 provided three radiocarbon dates, sediment accumulation rates, and pollen data (Brush in this volume). An additional radiocarbon date was obtained from core DC-1.

Pre-Holocene Time. Deposits of pre-Holocene age were found in only one core from the Duck Creek area. The lack of data for this period of time prohibits correlation to other cores. A sand unit

FIGURE 45

Summary Pollen Diagram for Duck Creek



interpreted to be pre-Holocene in age is seen in core DC-1 at 205-336 cm, underlying a peat deposit that was dated at 11,480 radiocarbon years BP. The lithology correlates to a dense sand (revealed by a dramatic increase in the number of hammer blows required to penetrate 6 inches) seen at 550 cm in borings for the bridge footings at Smyrna Landing (DelDOT) and in nearby wells (Delaware Geological Survey). The shallow occurrence of the pre-Holocene sand in core DC-1 suggests that the core location is marginal to the axis of the deeply incised (at least 550 cm) antecedent stream valley.

A peat deposit overlies the pre-Holocene sand in core DC-1 from 11,480 BP until approximately 500 BP. The pre-Holocene radiocarbon date is supported by the pollen assemblage, particularly in the abundance of spruce pollen, (Brush, personal communication). The LOI population of this unit, which also occurs later in cores DC-2 and DC-3, identifies a Palustrine wetland, but cannot distinguish whether Emergent or Forested. The abundant pollen of ferns (Figure 45) and the large wood fragments in the core sediments at this depth also suggest a Forested wetland.

Pre-5750 to 2250 BP. Nearly 50 cm of sandy mud lies under the 5750 BP radiocarbon horizon in core DC-3, showing that a wetland environment occupied the locality for an undetermined amount of time between 11,480 BP and 5750 BP. Muddy sand and sandy mud units at the base of cores DC-2, DC-3, and DC-4 correspond statistically to a Riverine channel environment (Block I, Figure 44). The channel was somewhat north of its present location from pre-5750 BP until 2250 BP. Later the channel migrated laterally (south) to its present position. The sediment accumulation rate of the channel unit in core DC-3 is 0.02 cm/yr. The laterally adjacent basal unit in core DC-6 consists of Low-organic mud, interpreted to represent a Riverine Emergent mudflat environment (dark stippled pattern, Figure 44). The absence of time control makes it impossible to be certain of the age of this unit; but since the Low-organic mud lithology is interpreted to be a tidal deposit, it would not be contemporaneous with the adjacent sandy units. It probably formed after some channel bank deposit, or sediments removed by channel erosion. Because the channel was probably 2 to 3 m deep, any lateral migration would have obliterated the Holocene record. Thus, the basal unit of core DC-5 (shown as Palustrine on Block I, Figure 44) was probably eroded away then replaced by a Riverine mudflat Low-organic mud unit (Block II, Figure 44) following tidal inundation.

2250 to 1300 BP. The peat unit occurring from pre-Holocene time at the location of core DC-1 spreads laterally to overlie the channel deposits in the middle of the valley at the locations of cores DC-2 and DC-3 as well. The localities previously occupied by the channel would have become available for colonization by Palustrine wetland species once the channel had migrated slowly to the south. Initially the plant community probably consisted of Emergent class herbaceous macrophytes that later gave way to larger forest vegetation migrating into the valley from the nearby uplands. This pattern of succession is supported by the early date on the peat unit (11,480 BP) at the valley margin near upland forests and the later date on the Palustrine peat at the valley axis (2250 to 1300 BP in core DC-3). The Palustrine wetland is represented by peat and occurs only north of the interpreted channel position.

A rapid twofold increase in the rate of sediment accumulation (0.04 cm/yr) occurs in the peat at 1700 BP (130 cm in core DC-3). The age versus depth plot of this deposit coincides with the line of the local relative sea level curve (Kraft 1976) suggesting the arrival of tidal water at this time. Units found laterally adjacent to the peat on the south of the channel in cores DC-4, DC-5, and DC-6 consist of Low-organic mud, interpreted as a tidal Riverine Emergent mud-flat (Block II, Figure 44).

1300 to 500 BP. The progressive influx of tidal mud led to a gradual, localized transition from peat to mud around 1300 BP (115 cm) in core DC-3 and somewhat later (higher up the core) farther from the valley axis in core DC-2 (Figure 36). Based on the LOI signature, this mud unit could be from any modern mud unit except for a Palustrine Forested environment. It is interpreted to represent a transition from Palustrine to Riverine.

Beginning about 700 BP, the Low-organic mud lithology, seen earlier in cores DC-4 and DC-5, occurs in all but core DC-1. It forms a wedge that is thicker at the valley axis and thinner towards the margins, suggesting a genetic relationship to the stream channel. This unit represents a Riverine wetland system of the Emergent class and Non-persistent subclass. A Palustrine wetland persisted along the elevated valley margin, as shown by the peat found in core DC-1 at this depth (Block III, Figure 44).

500 BP to Present. Around 500 BP a localized deposit of peat formed along the axis of the stream valley above the Low-organic mud, seen in cores DC-3 and DC-6 (Figure 36). Statistically this unit corresponds to a Palustrine wetland system of an undetermined class. It is interpreted to represent a localized riparian Palustrine Emergent wetland, which evolved as emergent vegetation became established

on the underlying mudflat (Riverine Emergent) margins of the channel. The number of pollen from grasses and other herbaceous emergents increased at this depth (25 to 40 cm) in core DC-3 (Figure 45), which corresponds to ages of 500 to 300 BP.

A mud unit is laterally adjacent to the peat along the valley margins, and overlies the peat from 300 BP to the present across the entire valley. This mud forms in a modern environment that is mapped as an Estuarine wetland system of the Flat (core DC-3) or Emergent class (Block IV, Figure 44). There is no lithologic change that signals the arrival of slightly saline tidal waters. Increasing relative sea level continues to supply tidal mud at present. The mud supports herbaceous emergents (grasses and sedges) which contribute organic detritus and trap tidal mud. The rate of sediment accumulation for transgressive deposits averaged 0.08 cm/yr, a 400% increase over the rate from the pre-transgressive Riverine sand.

Summary. Sedimentary deposits at the Duck Creek locality represent three different wetland systems. Riverine wetlands have occupied the area from before 5750 BP to the present, Palustrine wetlands existed north of the channel from 11,480 to 500 BP along the valley wall and from 2250 BP to 1300 BP in the center of the valley, and Estuarine wetlands have occupied the area for at least 500 years. Tidal influence began in the region around 1700 BP. The arrival of brackish water is estimated to coincide with the base of the Estuarine wetland deposit at around 500 BP. The modern Estuarine Emergent wetland (National Wetlands Inventory 1987 map of Smyrna, DE) is dominated by freshwater grasses and sedges, including common reed, big cordgrass, and bulrushes.

The St. Jones River Locality

The Holocene sequence of wetlands at the St. Jones River locality is presented below from the oldest known environment to the modern and illustrated by a schematic diagram (Figure 46). As on the cross-section, two different lines of section are shown on the diagrams. Refer to the cross-section for scaled lateral and vertical relationships (Figure 39) and Appendix V for lithologic detail from individual core logs. Analyses of core SJ-3 provided pollen data, three radiocarbon dates, and the time scale for calculations of sediment accumulation rates (Brush in this volume). Two additional radiocarbon dates are also available: one from core SJ-1 and one from core SJ-6.

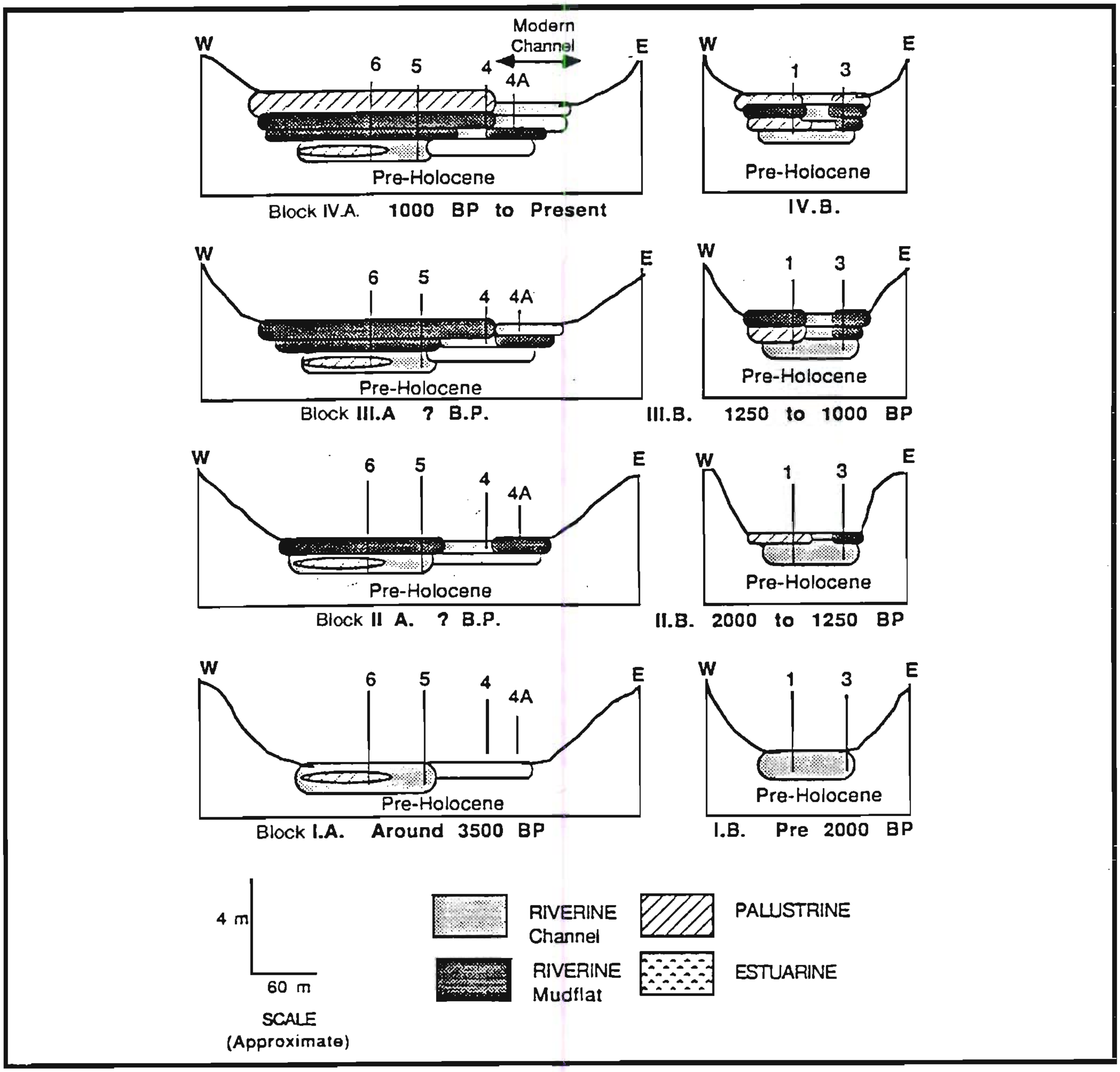
Pre-Holocene. Radiocarbon dates do not support a pre-Holocene age for any of the units found here. However, data on the lithology of pre-Holocene units were collected from field inspection of a Columbia Formation outcrop, from nearby well records (Delaware Geological Survey), and from boring records for the Route 10 bridge (DelDOT). The occurrence of channel sediments identical to the pre-Holocene deposits, but of a much younger radiocarbon age, strongly supports the erosion and reworking of pre-Holocene age sands into Riverine wetland channel deposits during the Holocene.

Mid-Holocene. Sand and sandy mud constitute the oldest deposits sampled at this location. Although the LOI values from these units are somewhat lower than those of the modern analog, they statistically identify a Riverine wetland channel environment (Block I, Figure 46). The difference in LOI values may be related to differences in the water regime. The modern Riverine regime is tidal, while the oldest Riverine units formed in a pre-transgressive (non-tidal), fluvial regime.

Radiocarbon dates from cores obtained along the large meander bend (cross-section A) show that the oldest Riverine deposits predate 3460 BP (334 cm in core SJ-6), while those from the meander cutoff (cross-section B) were formed sometime before 1890 BP (300 cm in core SJ-1) and 1920 BP (330 cm in core SJ-2). The time equivalence of the Riverine units in cross-sections A and B can not be determined on

FIGURE 46

Development of Wetlands at St. Jones River



the basis of the available age data, although the dense, compact nature of the basal units in cores SJ-5 and SJ-6 suggests that cross-section A may be somewhat older than cross-section B. In addition, the age versus depth plots for the dated deposits indicate that the oldest pre-3500 units formed in a pre-transgressive, fluvial water regime. Local relative sea level was 4 m below Mean low sea level at 3500 BP (Kraft 1976), while the sand deposits are less that 2.5 m deep. Age versus depth plots for the younger channel deposits from core SJ-3, as well as, other lithologic evidence support a transgressive tidal origin. This also suggests a younger age for the Riverine units of cross-section B than those of cross-section A. The meander channel may have been abandoned coincident with the transgression of tidal water into the area in approximately 2000 BP.

Cross-Section A

Beginning in 3500 BP, a small Palustrine wetland occupied the location of core SJ-6, succeeding the Riverine channel environment. Riverine deposition continued in the adjacent channel, sampled by core SJ-5. Sometime after 3500 BP, channel deposits of the Riverine system once again reoccupied the location of core SJ-6, demonstrating some lateral channel migration (Block I, Figure 46).

Overlying the Riverine channel deposits in cores SJ-5 and SJ-6 is a wedge of compact mud with very low LOI values. This Low-organic mud is interpreted to represent a Riverine, Emergent class wetland (mudflat). The composition, geometry, and vertical position of the unit between two units of a statistical Riverine signature support that interpretation. Laterally adjacent channel sands of the Riverine system occur in core SJ-4 at this depth (Block II A, Figure 46).

The Low-organic mud wedge is overlain by a mud unit whose LOI values correspond to those of modern Riverine mud deposits. Riverine channel sands are present in core SJ-4A at this depth (Block III A, Figure 46). The Riverine mud is overlain by peat and mud deposits of the modern Palustrine system and Emergent class (National Wetlands Inventory 1987 map of Dover, DE). The wetland succession to Palustrine represents the colonization of the Riverine mudflats by Emergent herbaceous vegetation (Block IV A, Figure 46).

Cross-Section B

Pre-2000 BP. The lithology and LOI values of the sand and sandy mud units at the base of cross-section B correspond statistically to a Riverine channel environment (Block I B, Figure 46). A Riverine channel environment persisted at the location of core SJ-1, but the location of core SJ-3 became occupied by the Low-organic mud representing a Riverine Emergent mudflat around 2000 years BP. These units are considered to have originated in a tidal transgressive environment because:

1) the coincidence of the age versus depth plots with the local relative sea level curve (Kraft 1976);

2) the occurrence of sand and mud interbeds, indicative of a tidal regime (Frey and Howard 1986); and

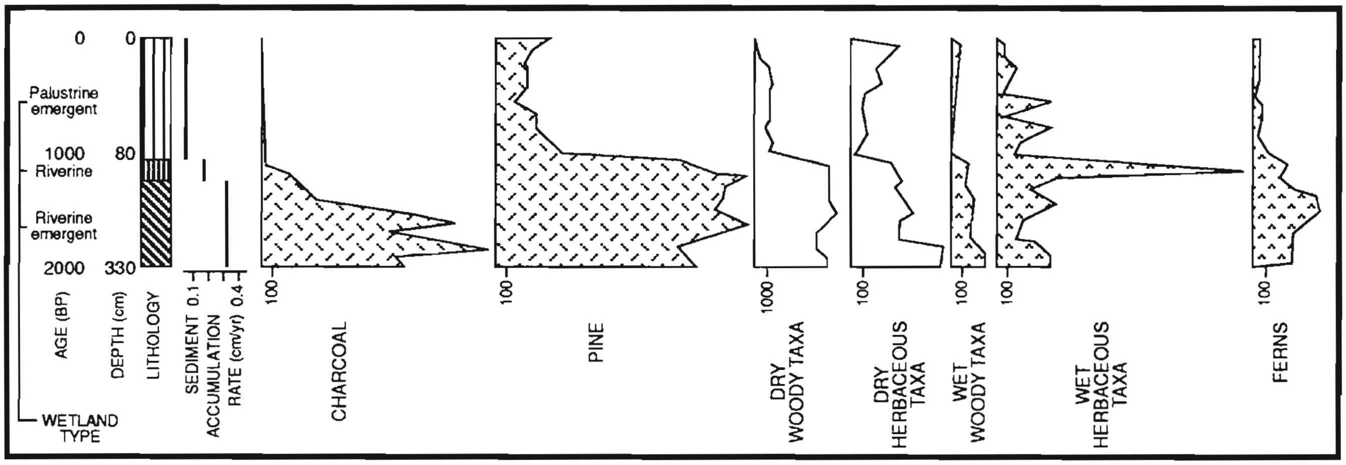
3) a very high (0.32 cm/yr) sediment accumulation rate (based on Brush in this volume).

2000 to 1250 BP. A Riverine Emergent wetland continued to occupy the channel margin at the location of core SJ-3 depositing Low-organic mud. Meanwhile, a Palustrine wetland became established and created the peat seen at the location of core SJ-1 (Block II B, Figure 46). The peat was gradually replaced by mud that reflects the upward growth rate of the Palustrine marsh was lower than that rate of deposition of tidal mud supplied in response to the continued rise in relative sea level.

1250 to 1000 BP. Mud indicating a Riverine channel environment overlies the Palustrine and Riverine Emergent wetlands dating until approximately 1000 BP (Block III B, Figure 46). The rate of sediment accumulation decreased to 0.20 cm/yr for this interval. Abundant charcoal and pollen of dry species appear in core SJ-3 from 2000 BP to 1000 BP (Figure 47) suggesting a 'dry' plant community that was populated by pitch pine - a fire-adapted, colonizing species (Brush in this volume). A progressive

FIGURE 47

Summary Pollen Diagram for St. Jones River



decrease in pollen abundances towards the top of the section may represent the demise of the dry community in response to the wetter conditions associated with, but lagging behind, tidal inundation.

<u>1000 BP</u> <u>to</u> <u>Present</u>. Beginning about 1000 BP (80 cm in core SJ-3), a Palustrine Emergent wetland became established and persisted to the present time forming the peat seen at the top of both cores in cross-section A (Block IV B, Figure 46). The change in wetland environment is accompanied by a rapid increase in the pollen abundances of 'wet herbaceous taxa' (for example, wild rice) for core SJ-3 (Figure 47). The modern Palustrine wetland environment has also formed the mud and peat units at the tops of the cores in cross-section B, except for core SJ-4A which is in the modern channel (National Wetlands Inventory 1987 map of Dover, DE).

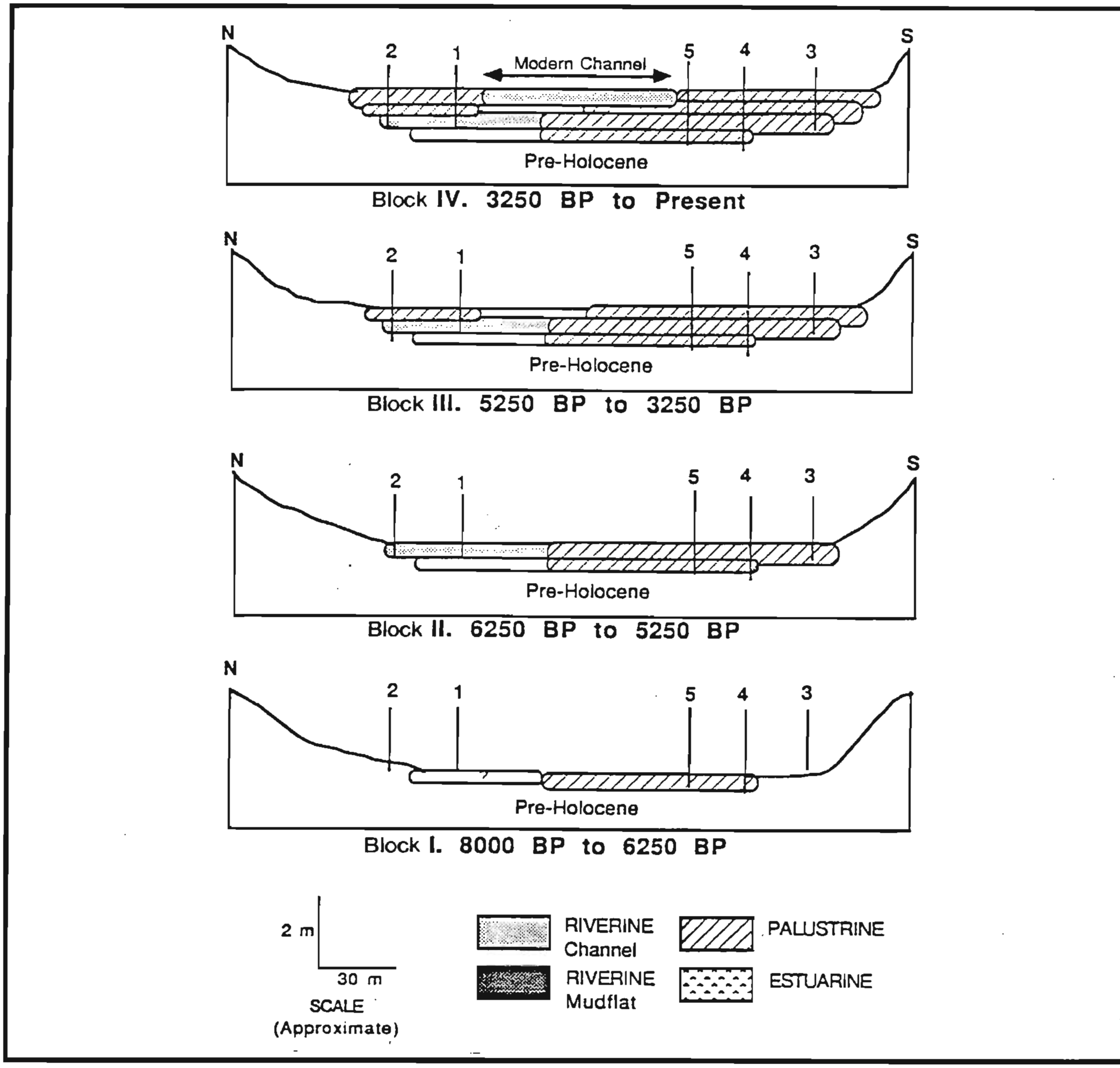
<u>Summary</u>. Although the cores obtained at the St. Jones locality were approximately the same length as those obtained at the other study localities, the rapid rate of sediment accumulation (0.07 to 0.32 cm/yr as compared to 0.02 to 0.08 cm/yr for the Duck Creek locality) resulted in a shorter sampled time interval. Units which correspond to Riverine wetland environments dominate the section, with localized episodes of vegetative colonization producing Palustrine wetlands at 3500 BP along the outside of the meander cutoff. The incursion of tidal freshwater into the area occurred around 2000 BP. A Palustrine Emergent wetland became widespread after 1500 BP, and is represented at the surface today (National Wetlands Inventory 1987 map of Dover, DE). The modern environment is a freshwater wetland dominated by erect, herbaceous hydrophytes (water-tolerant plants), producing a mixed plant community of narrow-leaved cattails, poison ivy, and other common emergent plants. Scattered shrubs and small trees of species such as willow, red maple, and wax myrtle are also present (Tiner 1985).

The Leipsic River Locality

The Holocene sequence of wetlands at the Leipsic River locality is presented below from the oldest known environment to the modern, illustrated by a schematic diagram (Figure 48). Refer to the cross-section for scaled lateral and vertical relationships (Figure 42) and Appendix V for lithologic detail from individual core logs. Analyses of core LR-1 provided pollen data, a basal radiocarbon date, and dates used to calculate sediment accumulation rates (Brush in this volume). An additional radiocarbon date was obtained from core LR-5.

FIGURE 48

Development of Wetlands at Leipsic River

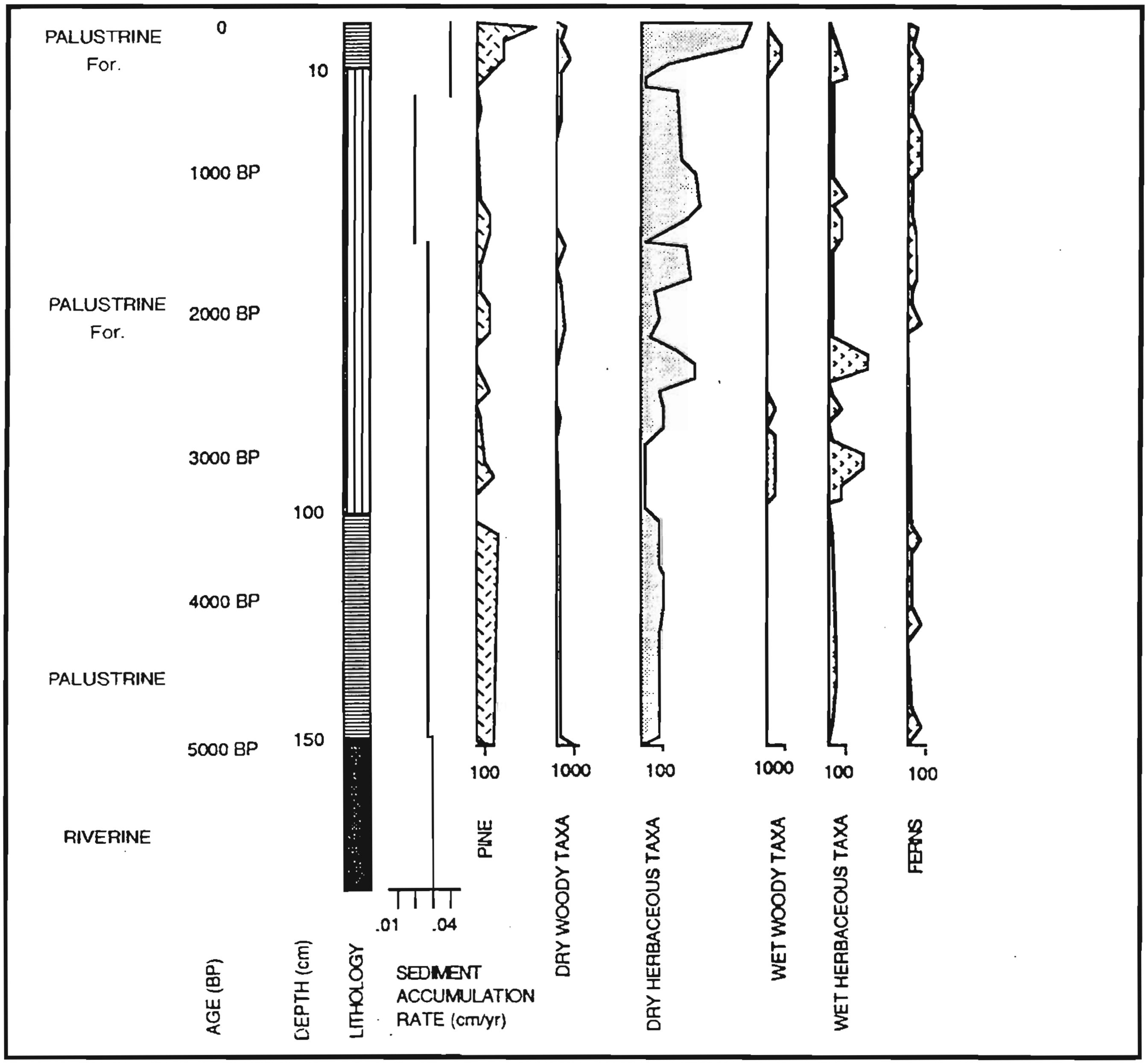


Pre-Holocene. No age is available for the compacted basal sand deposits in cores LR-2 and LR-4. Thus, they may represent either in-situ pre-Holocene units or erosion and redeposition by fluvial action in Holocene time. The units correlate with deposits interpreted to be pre-Holocene on the basis of their lithology and density (number of hammer blows required to penetrate one foot) encountered in bridge borings drilled a few kilometers up the stream valley at Garrison's Lake (DelDOT).

8000 to 6250 BP. A basal mud dated to 8000 BP occurs in core LR-5 and above the 'pre-Holocene' sand in core LR-4. LOI values for the unit correlate to an unknown class Palustrine wetland

FIGURE 49

Summary Pollen Diagram for Leipsic River



(Block I, Figure 48). The mud-forming environment was replaced by a peat-forming environment at a time which has no age control, but is somewhat older than a 6230 BP channel deposit in a laterally adjacent core.

6250 to 5250 BP. Basal sandy mud deposits in core LR-1, overlie the 'pre-Holocene' sand in core LR-2 represent deposition in a Riverine system wetland on the basis of their sand content and LOI value (Block II, Figure 48). The base of both units contain sand lenses probably derived from the reworking of underlying sands. The basal radiocarbon date of 6230 BP in core LR-1 shows that the channel was slightly north of its present position for a portion of mid-Holocene time (6230 to 5250 BP). The lack of pollen from this unit suggests a period of fluvial flooding (Figure 49; Brush in this volume). The sediment accumulation rate for the sandy mud in core LR-1 is 0.03 cm/yr.

The other cores record peat deposition at a depth adjacent to the Riverine sands. The statistical analysis of the LOI values for these peat units indicates a Palustrine Emergent environment (Block II, Figure 48) such as the modern wetland at the Saint Jones River locality.

5250 to 3250 BP. Lateral channel migration resulted in the end of Riverine channel deposition and the beginning of mud deposition from 5250 BP to 3250 BP in core LR-1. Equivalent mud units are seen in the other Leipsic River cores at slightly shallower depths. Statistical analysis of the LOI values identify this unit as Palustrine wetland environment, but cannot distinguish between the Emergent and Forested classes (Block III, Figure 48). The lithologic transition from Palustrine peat to Palustrine mud seen in the three cores obtained south of the channel (cores LR-3, 4, and 5) could reflect two possible environmental changes, either a relative increase in fluvially supplied mud, suggesting perhaps increased stream discharge and a wetter climatic regime, or a relative decrease in the in-situ organic productivity, suggesting a drier climate. The decreased rate of sediment accumulation (0.0275 cm/yr) and palynologic evidence support the latter. Although some pollen of ferns, mosses, and grasses is present (Figure 49), the predominate pollen signature is of 'dry woody' (oak, hickory, and pine) and 'dry herbaceous' taxa. This indicates the environmental transition from an Emergent to a Forested environment.

3250 to 1500 BP. By 3250 BP in core LR-1, a Palustrine Forested wetland had been established, depositing a highly organic peat above the Palustrine mud in all of the Leipsic River cores (Block IV, Figure 48). The peat occurs at somewhat lower depths, and therefore may be slightly older, along the valley margins (LR-2 and 3) where trees succeeded from the wooded uplands. Following an interval of no pollen, representing fluvial flooding (Brush in this volume), the pollen abundances for this unit are greatly increased over those of older deposits (Figure 49). The occurrence of wild rice, water lily, alder, birch, and ash pollen indicates a wetter interval, accompanied by a slight increase in the sediment accumulation rate (0.028 cm/yr). The presence of 'dry' species such as grasses, ragweed, goldenrod, oak, and hickory suggests, however, that the Palustrine Forested environment increased the productivity of both wet and dry species. Increased numbers of trees and shrubs supplied abundant organic detritus to the peat. The time of increased pollen deposition, resulting perhaps from wetter conditions, is not due to the incursion of transgressive water due to the rise in relative sea level, as the plots of the sediment age versus depth do not coincide with the relative sea level curve (Kraft 1976).

1500 to 500 BP. Around 1500 BP (40 cm in core LR-1) the pollen concentration sharply increases, corresponding to a decrease in the rate of sediment accumulation (0.020 cm/yr). Wet species such as cattail, wild rice, birch, and willow disappear from the pollen assemblage (Figure 49), which along with the reduced sediment accumulation, suggesting a reduction in the available moisture. No lithologic change is seen at this time, interpreted to mean that the productivity of the 'dry woody' species (for example, oak, hickory, maple) was adequate to maintain the supply of organic detritus so that peat deposition persisted. The LOI values show a progressive decrease towards the top of the peat unit in all of the Leipsic River cores, representing a reduction in the organic contribution within a Palustrine Forested wetland (Block IV, Figure 48).

500 BP to Present. An abrupt twofold increase in the rate of sediment accumulation (to 0.04 cm/yr) is seen at 500 BP (20 cm in core LR-1), corresponding to a renewed 'wet' pollen assemblage (Figure 49). This is interpreted to represent the arrival of tidal waters in to the area, and coincides with ages and depths on the local relative sea level curve (Kraft 1976). The increase in water level and the deposition of tidally supplied mud gradually overwhelmed the in-situ production of organic detritus, creating the lithologic unit of mud found at the top of cores LR-1, LR-2, and LR-3. Localized areas of restricted circulation permitted the continued deposition of peat at cores LR-4 and LR-5. A 5 cm bed of muddy sand

near the top of core LR-5 represents a Riverine subtidal channel deposit probably formed at elevated water levels as the channel continues its slow southern migration. The modern environment is mapped as a Palustrine Forested wetland flooded seasonally by fluvial action and less often than daily by tidal action (National Wetlands Inventory 1987 map of Smyrna, DE). Vegetation consists of green ash, red maple, and black gum, with some black willow, American holly, various oaks, Atlantic white cedar, and Loblolly pine. Emergent grasses and sedges may be established where the forest canopies opens (Tiner 1985).

Summary. Palustrine wetlands have existed on the south side of the present Leipsic River channel since at least 8000 BP according to radiocarbon dates, and around 5250 using ages determined from pollen influxes. (The lack of correspondence between the dates and depths to the local relative sea level curve (Kraft 1976) supports a riparian, non-transgressive environment of formation for these wetlands.) Riverine channel deposits have been present from at least 6250 BP to modern time. Tidal water reaches this locality only 500 BP.

SUMMARY COMPARISONS OF THE THREE WETLAND LOCALITIES

Channel Migration Rates

The lateral migration rate of the channels was approximated by dividing the map distance between subsurface Riverine deposits and the modern channels by the elapsed time in radiocarbon years. The rates obtained are roughly equivalent for the three study areas, ranging from a minimum of 0.006 m/yr to a maximum of 0.03 m/yr. All of the rates are at least one order of magnitude smaller than average rates of 0.32 m/yr from freshwater tidal wetland channels cited by Garofalo (1980).

The Pollen Record

A comparison of the pollen records of the three localities shows little temporal equivalence in the major shifts in vegetation. This suggests that the pollen signature records local conditions, rather than regional patterns of climate change. Vegetation changes were related to the local tidal transgression controlled by distance from the Delaware Bay and antecedent topography and local patterns of wetland succession.

Rates of Sediment Accumulation

Differences between the study areas are also evident in the rates of sediment accumulation for each lithologic interval (Table 10). The absence of any obvious pattern in the rates of sediment accumulation supports the localized nature of deposition in wetland environments.

CONCLUSIONS

The Loss-On-Ignition Method

The organic content of wetland sediments as indicated by their LOI values provided a method whereby sedimentary deposits formed in different modern depositional subenvironments could be statistically identified and distinguished from one another. Statistical methods used to compare LOI populations included the Analysis of Variance and the Mann-Whitney ranked median test, which resolved populations at the 0.05 significance level and yielded 95% Confidence Intervals for the population means or medians, respectively.

TABLE 10

Sediment Accumulation Rates for Radiocarbon Dated Wetland Cores

Site	Core	Lithology	Water Regime	Wetland System	Wetland class	Environment of Deposition	Sediment Accumulation Rate cm/yr
Duck Creek	DC-3	Sandy Mud	fluvial	RIVERINE	Unconsolidated bottom	channel	0.020
		Peat	fluvial	PALUSTRINE	Forested	marsh	0.040
		Mud	tidal	PALUSTRINE/ RIVERINE	Emergent?	transitional	0.080
		Low-organic Mud	tidal	RIVERINE*	Emergent*	mudflat	0.086
		Peaty Mud	tidal	PALUSTRINE	Emergent	marsh	0.150
		Mud	tidal	ESTUARINE	Flat	mudflat	0.067
St. Jones River	SJ-3	Low-organic Mud	tidal	RIVERINE*	Emergent*	mudflat	0.320
		Mud	tidal	RIVERINE	Unconsolidated Bottom	channel	0.200
		Peat	tidal	PALUSTRINE	Emergent	marsh	0.070
Leipsic River	LR-1	Sandy Mud	fluvial	RIVERINE	Unconsolidated Bottom	channel	0.030
		Mud	fluvial	PALUSTRINE	?	marsh	0.028
		Peat	fluvial	PALUSTRINE	Forested	marsh	0.028
		Peat	fluvial	PALUSTRINE	Forested	marsh	0.020
		Peat-to-Mud	tidal	PALUSTRINE	Forested	marsh	0.040

* = inferred

Lithologically heterogeneous LOI populations from three modern wetland systems (Riverine, Estuarine, and Palustrine) were distinguished from each other at the 0.05 significance level. The large wetland group systems were then subdivided according to lithology to provide a means for identifying the paleo-wetland environment of deposition for a given lithologic unit. Populations of such lithologically heterogeneous LOI values could then be recognized at both the class level and the subclass level of wetlands classification. This allowed for the correlation of LOI value, wetland classification, and depositional subenvironment (channel, mudflat, or marsh). These correlations were used to determine the sequence of wetland environments represented by subsurface sediments at the core localities. Paleoenvironmental interpretations made using the LOI method were supported and enhanced by pollen data.

One lithologic unit could not be classified using the LOI method because it was not represented in the surface environments sampled. However, knowledge of wetland plant communities and classification models permitted the depositional subenvironment of the Low-organic mud to be hypothesized even though it was not represented in the sampled modern record.

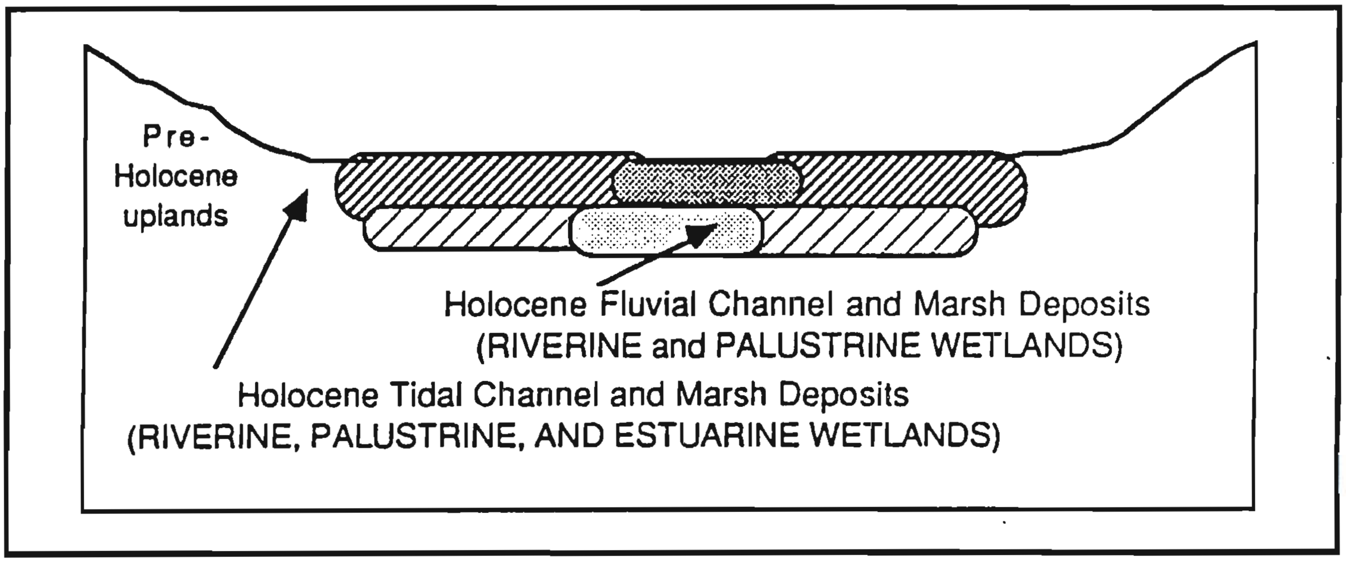
Pollen data supported LOI wetland identifications and allowed for two conclusions to be reached. First, the synchronous shifts in the pollen assemblages and in lithology suggested that they were both recording the same genetic processes. Second, the differences in the ages of shifts in the pollen assemblages from the three localities indicated that the pollen signature is a local rather than regional. Variations in the rate of sediment accumulation for any given lithology emphasizes the localized nature of sediment deposition in wetland environments.

Holocene History

Cores from three different wetlands reveal a Holocene history that is conceptually logical and supported by evidence. Holocene freshwater fluvial channel and marsh deposits of the Riverine and Palustrine wetland systems, respectively, overlie pre-Holocene sand units encountered at depths of

FIGURE 50

Generalized Development of Wetlands in Delaware



approximately 150 cm in the Leipsic River area, and 205 cm in the Duck Creek area (not encountered in cores from the St. Jones River area). The date of the tidal transgression into each of the three localities was approximated by considering the local relative sea level curve published by Kraft (1976), increases in the rates of sediment accumulation (which increase the ratio of mud to organic matter), and pollen analyses. The ages are estimated to be 2000 BP, 1700 BP, and 500 BP for the St. Jones River, the Duck Creek, and the Leipsic River localities, respectively. Note that the St. Jones locality has the longest tidal history and the thickest Holocene section, while the Leipsic River locality has the shortest tidal history and the shallowest Holocene deposits.

The marine transgression brought tidal units landward and upward in space and time, and deposited them over older fluvial units on the pre-Holocene basement. Between 0.4 and 2.0 m of freshwater Holocene, fluvial deposits of the Riverine and Palustrine wetland systems are overlain by between 0.2 and 4.7 m of tidal channel and marsh deposits of the Riverine, Palustrine, and Estuarine wetland systems. The schematic relationship between the pre-Holocene transgression surface and the Holocene fluvial and tidal deposits is depicted in Figure 50.

Finally, in light of the continued relative sea level rise along the Delaware coast, the modern occurrence of Estuarine wetlands at the Duck Creek locality provides a model with which to predict the future occurrence of Estuarine wetland deposits at the St. Jones and Leipsic River localities.

PALEOBOTANICAL ANALYSES OF THREE TIDAL STREAM VALLEYS ALONG THE PROPOSED STATE ROUTE 1 CORRIDOR, KENT COUNTY DELAWARE

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INTRODUCTION

The purpose of this study was to reconstruct the vegetation and climatic conditions over several centuries along tidal stream valleys occupied by native American populations prior to European settlement. These stream valleys are adjacent to archaeological sites along the corridor of the proposed State Route 1.

The method used for reconstructing vegetation and making inferences regarding climate change is to construct vertical profiles of pollen, seed, and charcoal extracted from sediments deposited in these tidal tributaries over long time periods, on the order of centuries and millennia. Pollen grains are produced by both terrestrial and aquatic plants generally in great abundance; when deposited in areas of high sedimentation where burial is rapid, preservation can be very good. Pollen grains are small (10 to 70 microns) light (specific gravities slightly greater than 1) particles. The majority of pollen are transported from the source trees and shrubs atmospherically, so that pollen preserved in sediments represents more or less the regional vegetation. Seeds on the other hand, because they are heavier and larger, are not transported as far, and are generally representative of the local vegetation. Whereas pollen grains are rarely identifiable to species, seeds can be related to the species taxon, and hence provide considerably more information with regard to vegetation type. Pollen grains and seeds together can provide a rather complete history of vegetation change.

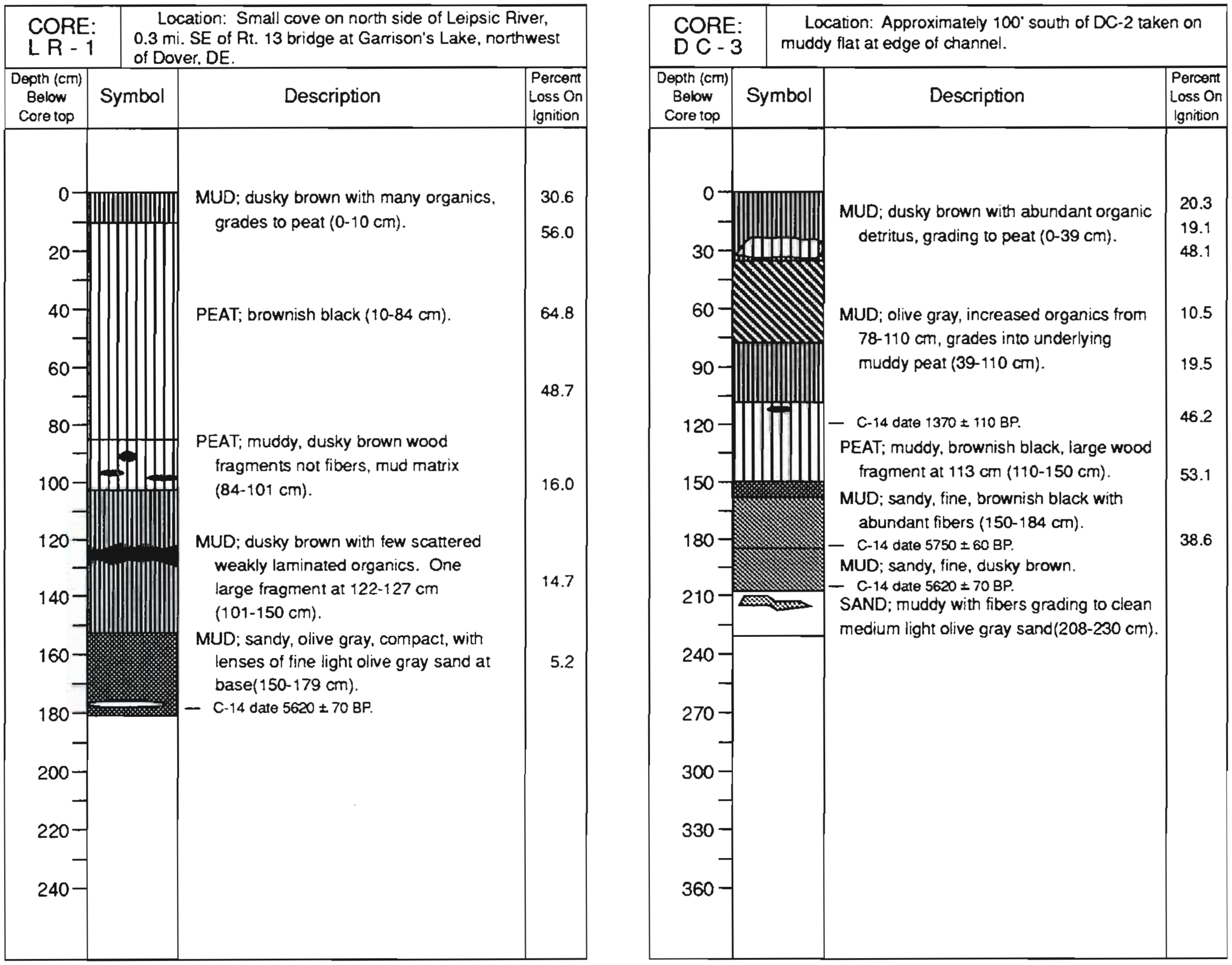
Because many plants have rather specific ecological requirements with respect to temperature and water availability, changes in the composition of fossil populations provide a record translatable to climatic change. Transfer functions have been described for plants to reconstruct past temperatures (for example Huntley and Prentice 1988), but not precipitation. However, if the pollen and seed composition of a particular horizon within a core changes from predominantly sedge to predominantly goldenrod for example, it is reasonable to conclude that there has been a change in water level due either to sediment filling or to a drop in the water table caused by decreased precipitation, even though quantitative assessments cannot be made. Such changes would be of fundamental economic and cultural importance to human societies.

METHODS

Three sediment cores were selected from among 31 collected by Elizabeth Rogers and James Pizzuto (in this volume) of the University of Delaware at three locations in northeastern Delaware (Figure 2). Sediment core DC-3 was analyzed from the Duck Creek locality (Figure 34), SJ-3 from the Saint Jones Creek locality (Figure 37), and LR-1 from the Leipsic River locality (Figure 40). The cores were collected

FIGURE 51

Stratigraphy of Cores Studied for Pollen



See Figure 47 for core SJ-3.

with a vibrocorer and are 220 cm long for DC-3, 180 cm for LR-1, and 425 cm for SJ-3. Stratigraphically, all three cores consist of alternating layers of mud and peat, with bottom layers containing sand (Figures 38 and 51). The cores are remarkably homogeneous and appear stratigraphically intact. Each core was split in two lengthwise, and the one-half of the core assigned for paleobotanical analyses divided into 1 cm intervals. Each 1 cm sample was stored in a plastic "Ziploc" bag at 4°C until processed for pollen and seed extraction.

Dating of Cores

Radiocarbon dates were obtained for three levels in core DC-3, the bottom level of LR-1, and three levels in SJ-3 (Figure 38). In addition, the European settlement horizon is identified in each of the cores based on an increase in ragweed pollen. With initial clearing of the land by the early settlers and ensuing intensive agriculture, ragweed which colonizes disturbed ground (Bazzaz 1974) increased rapidly and, being a prolific pollen producer, resulted in a dramatic increase in the amount of ragweed pollen deposited in sedimentary basins. Along with the increase in ragweed, the flux of arboreal pollen into the sediments

TABLE 11

Sedimentation Rates for Pollen Cores

Core	Depth of Sediment (cm)	Date (BP)	Sedimentation Rate (cm/ yr)
DC-3	17 120-124 204-208	267 (pollen) 1370 ± 110 (C^{14}) 5620 ± 70 (C^{14})	0.064 (0 - 17 cm) 0.095 (17 - 122 cm) 0.02 (122 - 206 cm)
LR-1	15 172-178	267 (pollen) 6230 ± 270 (C^{14})	0.06 (0 - 15 cm) 0.03 (15 - 175 cm)
SJ-3	23 76-80 156-160 336-340	267 (pollen) 1040 ± 120 (C^{14}) 1360 ± 100 (C^{14}) 1920 ± 70 (C^{14})	0.09 (0 - 23 cm) 0.07 (23 - 78 cm) 0.25 (78 - 158 cm) 0.32 (158 - 338 cm)

changed with deforestation of the land. Because oak is a dominant tree in eastern USA and the relationship between basal area of oak trees and pollen in surface sediments in given areas is fairly close (Brush and DeFries 1981), ratios of oak to ragweed pollen are used along with the percentage of ragweed pollen as markers of initial European settlement (Brush 1984). The actual time of settlement can be obtained from historical documents, and will vary in different places, because settlement was not synchronous, regionally. The time of initial settlement for north central Delaware is approximately 1720. Consequently, the stratigraphic horizon where ragweed becomes an important component of the pollen profile is dated 1720.

The dated horizons in these cores show high variability in sedimentation rates both within and between cores (Table 11). Core SJ-3 has the highest sedimentation rate with a date of 1920±70 radiocarbon years before the present at 336-340 cm depth. The European agricultural horizon is also at a lower depth in this core, indicating a higher sedimentation rate since European settlement also at this location.

When sedimentation is highly variable in a depositional basin, it is necessary to convert concentrations (number contained in a volume of sediment) of fossilized components (pollen, seeds, etc.) to influxes (number deposited per area per year). If, for example, the sedimentation rate is 0.1 cm/yr, 100 pollen grains in a cm^3 means that 100 grains were deposited in 10 years or 10 grains in one year, whereas if the sedimentation rate were 0.01 cm/yr, 100 grains in 1 cm^3 means 100 grains deposited in 100 years or 1 grain per year. The high variability of sedimentation in tidal tributaries suggests that average rates calculated between dated horizons does not provide a reliable means for calculating influxes. Consequently, sedimentation rates have been calculated for each 1 cm interval of the core by adjusting the average sedimentation rate according to the ratio of pollen concentration to sediment concentration in each 1 cm interval (Brush 1989). The method is based on the assumption that pollen input into a basin is relatively uniform if species composition has not changed, and if the area of vegetated landscape is uniform. If the rate of sediment accumulation increases, the concentration of pollen in the sediment will be correspondingly less and if sediment accumulation decreases, pollen concentration will be correspondingly lower.

The sedimentation rate for individual core segments can then be calculated using the following equation:

$$r = \frac{N}{n} R,$$

where r = the sedimentation rate for an individual core segment,
N = the average number of pollen grains per core segment,
n = the number of pollen grains in the core segment,
R = the average sedimentation rate of a core interval (d/t),
d = the length of a dated core interval, and
t = time in years.

The following procedure is used to determine values for N and n:

1) cut the sediment core into equal segments (for example, 1 cm);

2) obtain average sedimentation rates throughout the core, using carbon-14, lead-210, and/or the identification of historically dated pollen horizons;

3) extract a known volume (for example 1 cm^3) of sediment from each core segment (for example, 1 cm) and weigh the sediment (g/cm^3);

4) extract the pollen from the entire volume of sediment using standard methods for pollen extraction (Faegri and Iversen 1975);

5) count all of the pollen in an aliquot (e.g., 0.1 cm^3) of all core segments (duplicate aliquots should be counted in order to estimate the experimental error);

6) calculate the number of pollen grains in the entire 1 cm^3 segment (number of grains/cm^3).

7) multiply the number of grains/cm^3 by the depth of the segment (e.g.,1 cm) to give the number of grains/cm^2;

8) add the number of grains/cm^2 for all segments between dated horizons and divide by the number of segments.

Once sedimentation rates are calculated, the number of years required for deposition of each 1 cm segment within a core is calculated by dividing the depth of the segment by the sedimentation rate. Chronologies assigning years to each depth level are then constructed for the entire core.

Extraction of Pollen

A volume of 1.5 ml of sediment was removed from each subsample analyzed from the core and treated with hydrochloric and hydrofluoric acids to remove carbonates and silicates. The sample was then treated with potassium hydroxide and boiled in an acetolysis mixture consisting of nine parts of acetic anhydride to one part sulfuric acid in order to clean the sample of humic and extraneous organic material. The residue was washed in glacial acetic acid, water, and ethanol, and the entire residue stored in 25 ml tertiary butyl alcohol. A measured aliquot from each subsample, generally 0.1 ml, was pipetted on a drop of silicone oil on a microscope slide and all of the pollen on the slide identified and counted, under 400x magnification. The influx value was then calculated by multiplying the numbers of pollen in the volume of sample (taking into account the dilution factor) by the appropriate sedimentation rate for that level of the core.

Extraction of Charcoal

Charcoal was retrieved with the pollen extraction and pieces of charcoal were counted on slides in the same manner that pollen was counted. Numbers of charcoal pieces were then multiplied by the sedimentation rate to give the charcoal influx or number of charcoal pieces deposited/cm^2/yr.

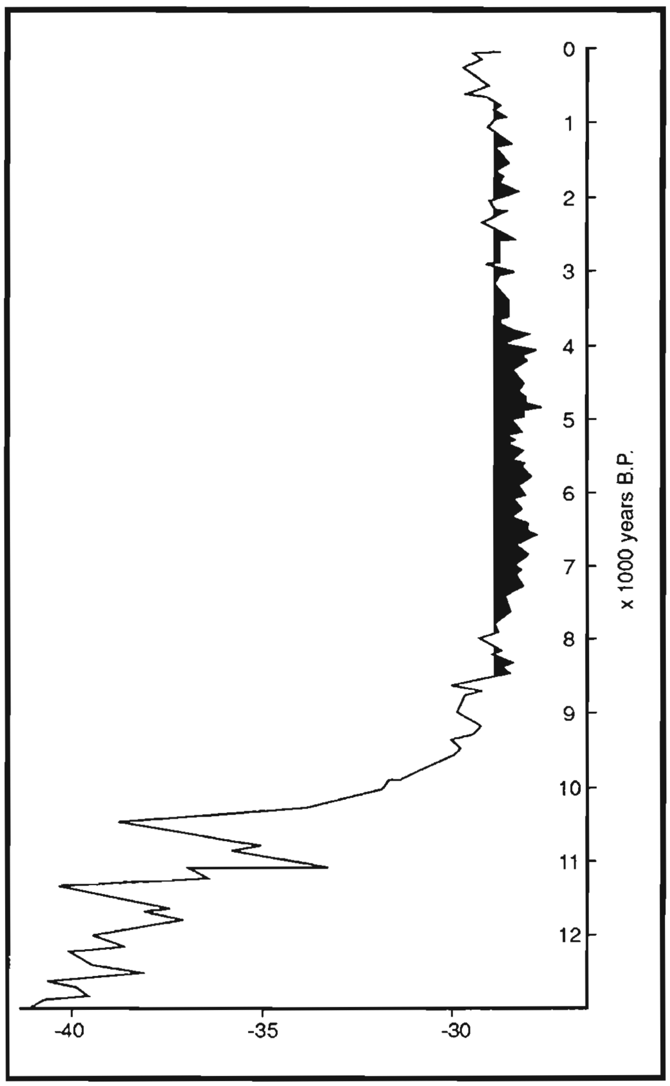
Extraction of Seeds

A volume of sediment from each subsample analyzed for seeds was removed from the subsample and submersed in 50 ml of 10% nitric acid in a graduated cup. The volume of sediment was measured by measuring the volume of liquid displaced to the nearest millimeter. The sediment is disaggregated by soaking in nitric acid (Godwin 1975; Birks and Birks 1980), after which it is washed through a column of nested 20 mesh (0.8 mm) and 60 mesh (0.25 mm) sieves. Seeds and other remaining material are then placed in water in a clear petri dish and examined under 15x to 40x magnification, using a binocular microscope. Seeds were isolated with forceps and stored in vials of water and formalin. All of the seeds in a sample were identified and counted, and influxes of seeds (number deposited/cm^2/yr) calculated by multiplying the number of seeds in the volume of sediment by the sedimentation rate for that particular level of the core.

FIGURE 52

Camp Century, Greenland

Ice Core Profile



(From Dansgaard 1981) Climate warmer than today is shown in black.

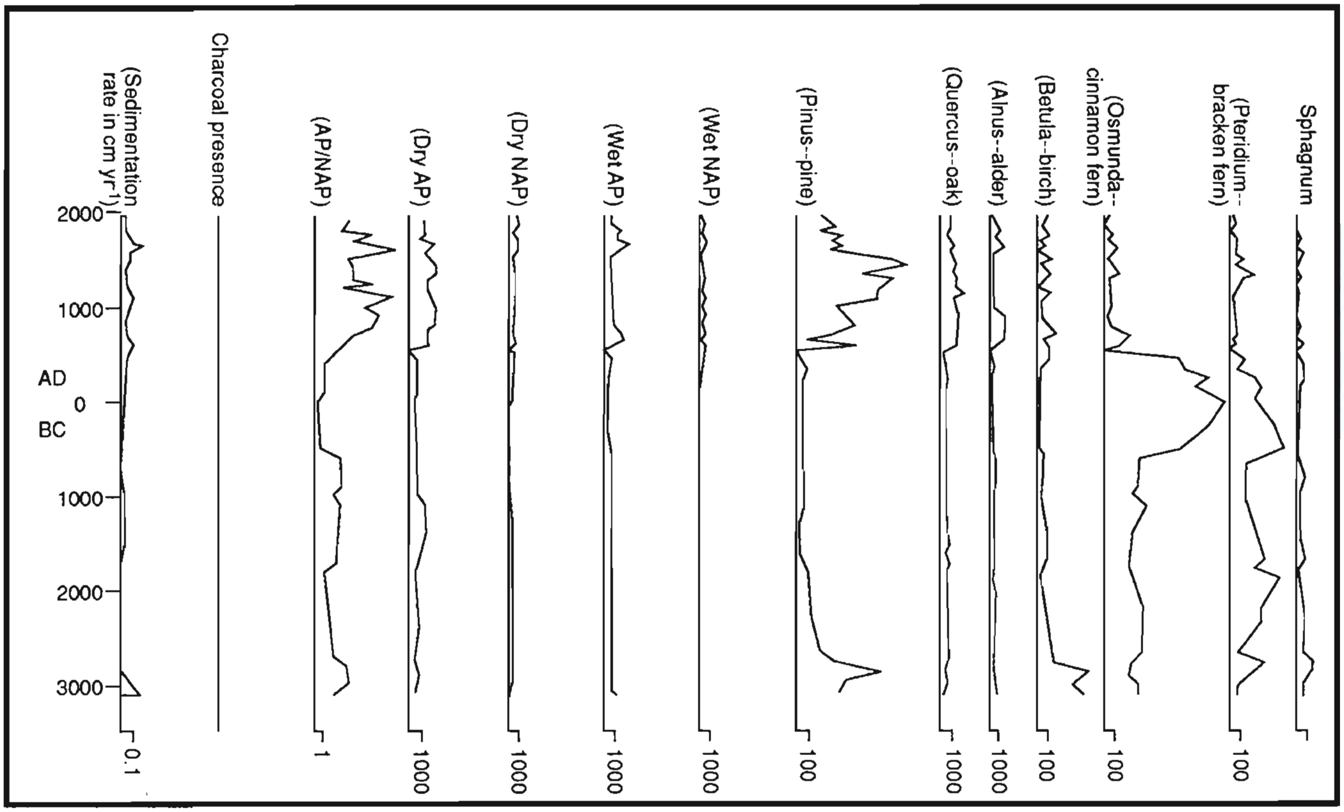
Analysis of Data

Core depths were converted to years using the chronologies constructed for each core. Samples were then arranged in a series of equal time intervals. The time interval depends on the resolution or sedimentation rate; time intervals were 50 years for DC-3, 100 years for LR-1, and 10 years for SJ-3. Sedimentation rates, charcoal, pollen and seed influxes were then plotted against a time axis of equal time intervals. This was done so that time series analyses of the data can be performed, and the results compared with other time series data, such as those recovered from ice cores or varved sediments.

A profile showing changes in the amount of oxygen-18 ($\delta^{18}O$) in the Camp Century core (Dansgaard 1981) is plotted alongside the pollen profile for each of the cores on the same time scale (Figure 52). The amount of oxygen-18 contained in ice cores is derived from precipitation in the area. Isotopic ratios in precipitation are sensitive to temperature. The greater the drop in temperature,

FIGURE 53

Pollen Diagram for Duck Creek Core DC-3



Calculated sedimentation rate and charcoal accumulation rate curves are also shown. AP - arboreal pollen; NAP - non-arboreal pollen.

the more condensation will occur and the lower will be the heavy isotope concentration relative to sea water. The departure of oxygen-18 in ice cores from its concentration in standard mean ocean water ($\delta^{18}O$) is used to calibrate the air temperature. For example, a $\delta^{18}O$ value of -10 indicates a sample with 1% less oxygen-18 than in sea water. Figure 52 is taken from Dansgaard (1981) and shows the $\delta^{18}O$ profile for the last 10,000 years in the Camp Dentury ice core from Greenland. The black areas indicate warm periods. Air temperatures were considerably colder than present 10,000 to 9000 years ago when the continental glaciers were retreating northward. The period from 7000 to 4000 years ago was warmer than at present. From 3000 years to the present is characterized by a greater number of oscillations. From 3000 to 2000 years ago climate was cooler, from 2000 to 1000 years ago warmer than the present, and from 1000 years to the present cooler. Historical records indicate that 1000 to 1200 AD was warm over most of the earth. This was followed by the Little Ice Age during which time the average global temperature decreased by 2°C.

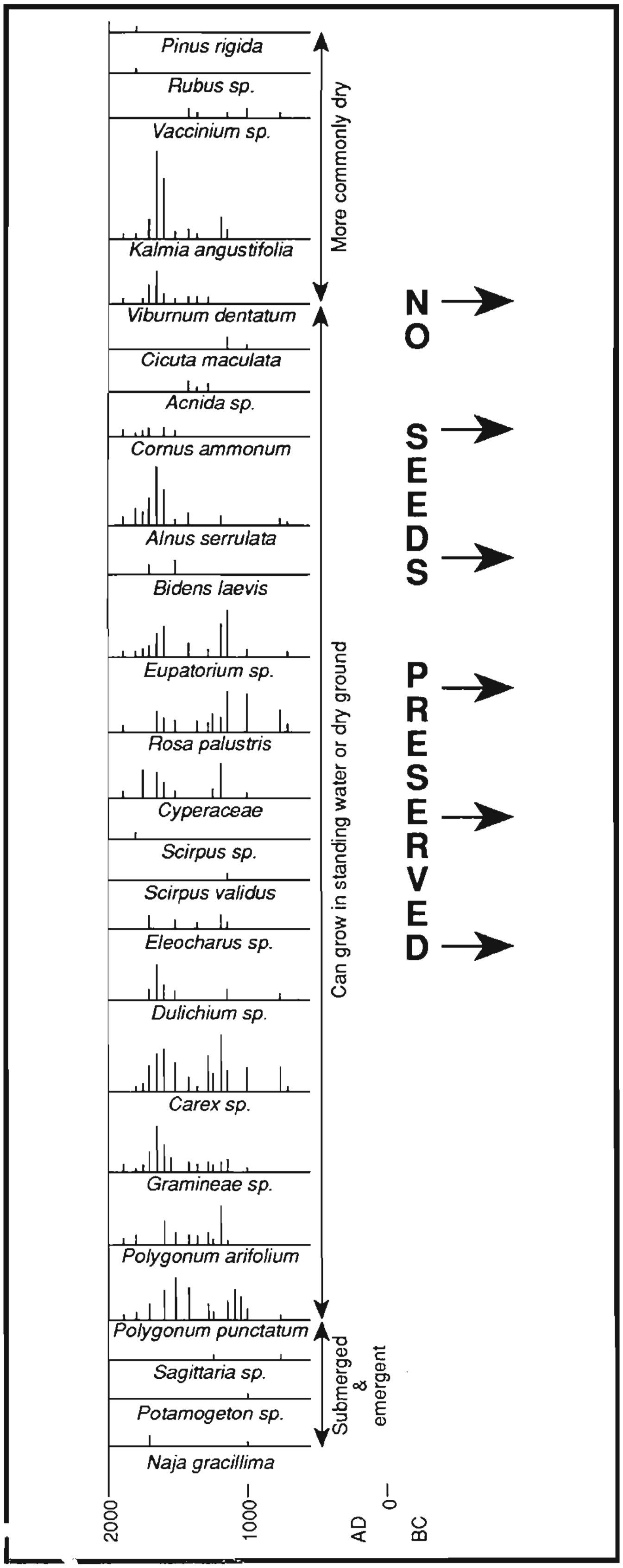
RESULTS

Duck Creek Core DC-3

Sedimentation Rates (Figure 53). Sedimentation rates are highest at the bottom of this core, and increase again about 1500 years ago. There is not much change after that time until approximately the time of European settlement, when the rate reaches 0.23 cm/yr for about 50 years. It then decreases to <0.1 cm/yr from about 1900 to the present.

FIGURE 54

Seed Diagram for Duck Creek Core DC-3



Charcoal (Figure 53). Although charcoal is present in many levels of the core, it is not present in any great abundance.

Pollen (Figure 53 and Appendix VI). The ratio of arboreal to non-arboreal pollen changes throughout the core, but most dramatically from 1500 years ago to the present, when arboreal vegetation dominated the landscape. This ratio is influenced by very large fluctuations in Pinus (pine) pollen and spores of Osmunda cinnamoneum (cinnamon fern). Apparently there were few trees on the landscape from 2500 to 2000 years ago. Pollen of all arboreal taxa increased 1500 years ago. Pine pollen was abundant about 5000 years ago, and tapered off from that time to about 3700 years ago, when the pollen influx was extremely low. Pine became the most important component of the landscape 1500 years ago, with largest influxes occurring from 1000 years ago to the time of European settlement. Quercus (oak) pollen is relatively uniform throughout the core until 1500 years ago when it increases, and remains uniformly higher to the present, with a slight decrease after European settlement. Alnus (alder) is uniformly unimportant until 1500 years ago, increases for 500 years, decreases for another 500 to 600 years, and increases again. Betula (birch), likely Betula nigra (river birch) at this locality, is high at the bottom of the core and has the same general distributional pattern as pine, tapering off to very low values, and then increasing 1500 years ago, and oscillating since that time. The other tree pollen identified in this core are listed in Appendix VI. Their occurrences are sporadic and influxes low. The ferns constitute the most important non-arboreal taxa. Cinnamon fern is important from 5000 to 2500 years ago, at which time influxes triple until 1500 years ago, when there is a drastic decrease in its abundance. Pteridium (bracken fern) is present in very low numbers 5000 years ago, then increases, decreases and increases to large populations about 3800 years ago. It then decreases somewhat, and reaches its greatest abundance 2500 years ago, coincident with the large increase in cinnamon fern. It is a minor component of the landscape after 1500 years, except for a period of about a century some 500 years ago.

The moss Sphagnum is present throughout, but never important. Other non-arboreal taxa present throughout the core are listed in Appendix VI.

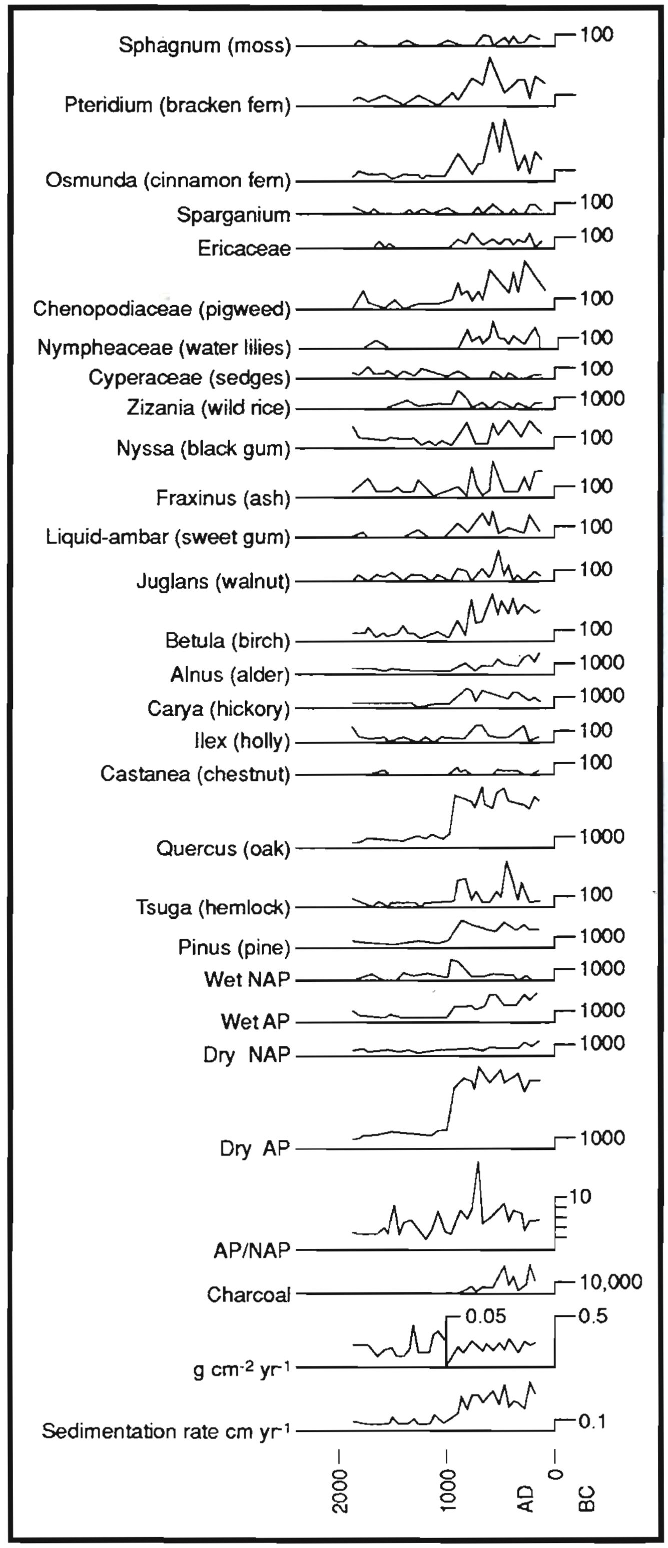
Seeds (Figure 54). Species are organized with those that grow only in standing water, either as submerged aquatics or emergents on the left side of the figure, followed by species that grow both in standing water and dry ground, with those with drier ranges to the right. On the far right, are plotted species which can grow in standing water, but are more commonly found on dry ground. There are no seeds present in sediments deposited prior to 1500 years ago. The graph shows a trend from predominantly wetter floras 1200 years ago to progressively drier about 400 years ago. Carex (sedge) produced extremely large numbers of seeds from 900 to 700 years ago, at which time Eupatorium, another sedge and Rosa palustris (marsh rose) were also abundant. These taxa become less abundant after 700 years ago. From 400 years ago to about the time of European settlement, Alnus serrulata (common alder) and Kalmia angustifolia (lambkill) became dominant. Although these plants can grow in open water, they can also grow permanently on dry ground.

Interpretation of Core DC-3

The pollen record indicates that for 1000 years from 2500 to 1500 years ago, conditions were dry with fire possibly frequent. The evidence for this is the large amount of spores of Pteridium (bracken fern), a fire indicator, present at that time, and the very low pollen influxes of all tree and shrub taxa. If there were frequent fires, pollen production could be expected to be low. Osmunda (cinnamon fern), although not a direct indicator of fire, does grow well in open areas of bare soil. Clark (1988) has shown that, due to transport and depositional processes, the absence of charcoal in sediment does not preclude fire. Low influxes of Pinus (pine) pollen during this interval and for some time prior to 2500 years ago, could be the result of fire if the species represented is Pinus taeda (loblolly pine) which is non-resistant to fire.

FIGURE 55

Pollen Diagram for St. Jones River Core SJ-3



Calculated sedimentation rate and charcoal accumulation rate curves are also shown. AP - arboreal pollen; NAP - non-arboreal pollen.

The next thousand years, from 1500 to 500 years ago, show a dramatic change both in the pollen and seed profiles indicating initially very wet conditions becoming progressively drier in more recent times. The ferns decrease dramatically, and pine becomes dominant. The seeds show a gradual progression from plants growing in standing water to those that grow generally in standing water to those that can grow on dry ground, as well as wet ground.

Saint Jones Creek Core SJ-3

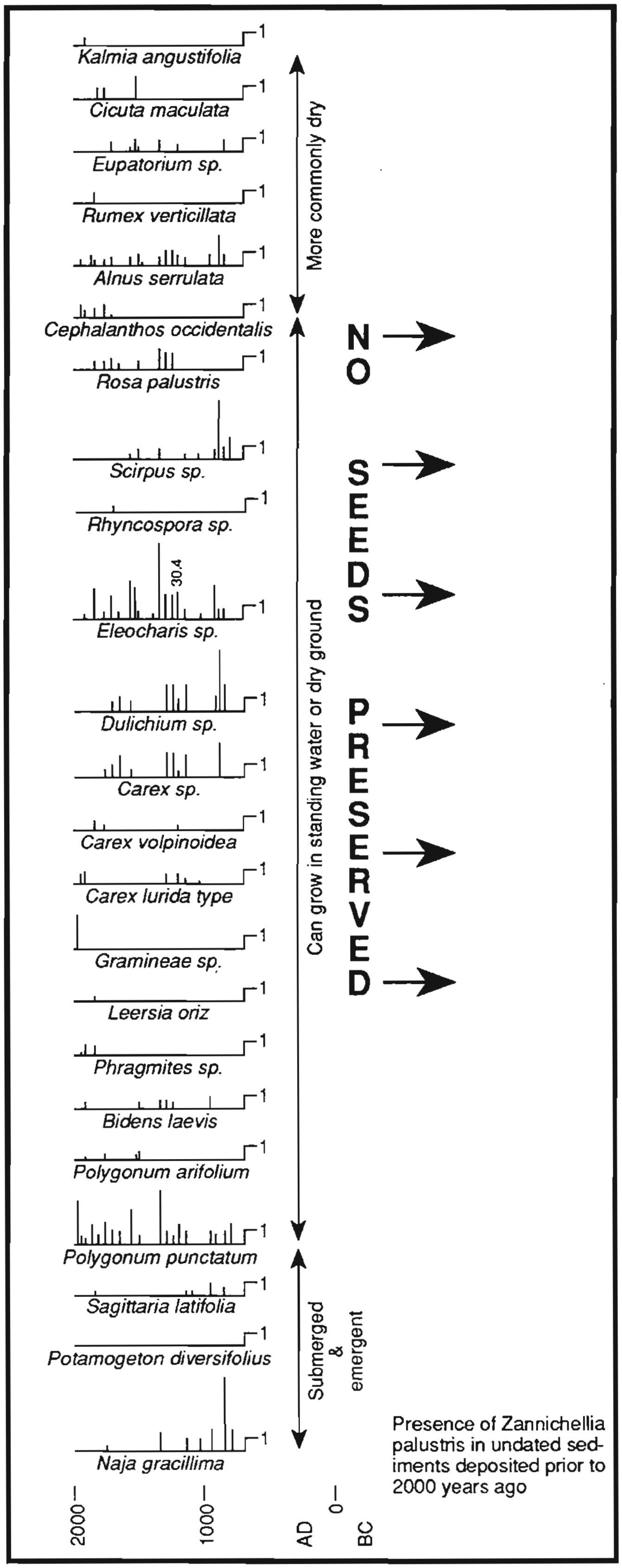
Sedimentation Rates (Figure 55). The average sedimentation rate in this core is very high (2000 years in 4 m of sediment). Sedimentation rates, both linear (cm/yr) and mass ($g/cm^2/yr$) show a dramatic decrease 1000 years ago. Sedimentation rates varied between 0.2 to 0.48 cm/yr for 1000 years from 2000 to 1000 years ago, and decreased to an average 0.1 cm/yr, with only a very slight rise during the last century.

Charcoal (Figure 55). The charcoal profile shows large influxes for about 500 years from 2000 to 1500 years ago. Influxes for the next 500 years are about 1/4 the amount of the previous 500 years, and become a very minor component of the sediment in the last 1000 years.

Pollen (Figure 55 and Appendix VI). The pollen profile shows a large decrease in pollen influxes of arboreal pollen 1000 years ago, but the non-arboreal pollen seems to be less affected. Tsuga (hemlock) as well as Pinus (pine) were present in fairly large numbers during the earlier 1000 years. A moderately diverse flora is represented in this core. The most common taxa are plotted in Figure 55 and other species which occur rarely and sporadically are listed in Appendix VI. Juglans (walnut), Fraxinus (ash), and possibly Nyssa (black gum) show less change 1000 years ago than the other tree taxa. Among the non-arboreal pollen, Cyperaceae (sedges) and Sparganium (burreed) show little overall change. However, the Nympheaceae (water lilies) essentially disappear, and the Chenopodiaceae (pigweed family) show a large decrease. The Ericaceae (blueberry

FIGURE 56

Seed Diagram for St. Jones River Core SJ-3



family) also drop out 1000 years ago, and do not reappear until 400 years ago and then only in small amounts. The ferns, Osmunda (cinnamon fern) and Pteridium (bracken fern) were both abundant from 2000 to 1000 years ago, and present in small numbers during the last 1000 years. Sphagnum, too, is uniformly present until 1200 years ago, when its occurrence becomes sporadic.

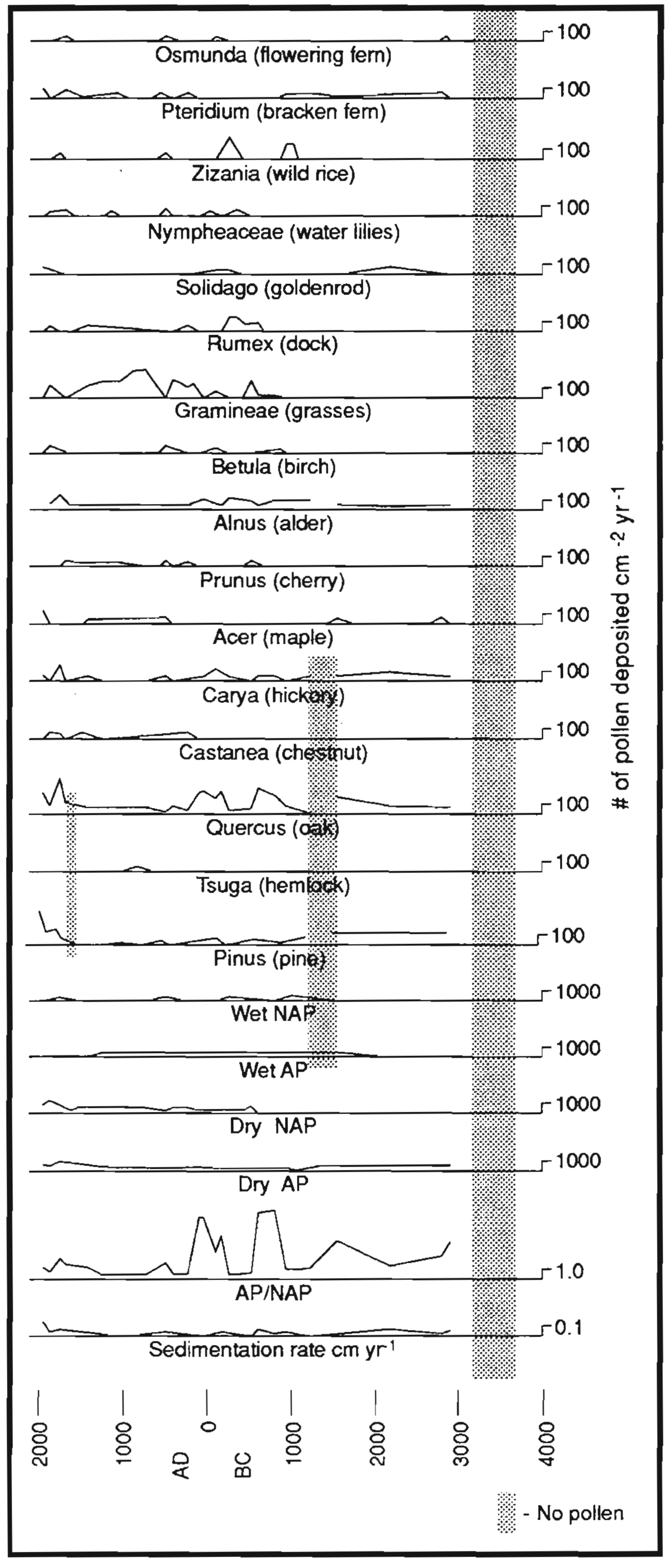
Seeds (Figure 56). Seeds of the submerged aquatics Zannichellia palustris (horned pondweed) and Najas gracillima (naiad) are present in undated sediments deposited prior to 2000 years ago. This is the only occurrence of Zannichellia in this core. There are no seeds preserved in sediment deposited from 2000 to 1200 years ago. From 1200 years ago to about 650 years ago, the plants represented by the seed populations include submerged aquatics, emergents and large numbers of sedges, particularly Eleocharis from 800 to 650 years ago. This is the same time when sedges and other "wet" plants were dominant in core DC-3. Gradually, these plants decreased in number, and other species such as Cephalanthus occidentalis (buttonbush), Rumex verticillata (dock) and others which can grow permanently on dry ground appear for the first time about 350 years ago.

Interpretation of Core SJ-3

The large amounts of charcoal and high sedimentation rates from 2000 to 1000 years ago, along with abundant spores of Pteridium (bracken fern), Osmunda (cinnamon fern) suggest that this was a dry period with frequent fires. However, fires were not sufficiently severe to affect flowering and pollination, as all of the species were producing abundant pollen during this time. The pine species could be Pinus rigida (pitch pine) which is fire resistant, and which can reproduce only with fire. This period was succeeded by extremely wet conditions, which probably began about 1200 years ago, when pollen of Zizania (wild rice) and seeds of submerged aquatics and emergents were most numerous. During the past 1000 years,, pollen influxes of all tree species decreased rather drastically, but the decreases were less severe for

FIGURE 57

Pollen Diagram for Leipsic River Core LR-1



Calculated sedimentation rate and charcoal accumulation rate curves are also shown. AP - arboreal pollen; NAP - non-arboreal pollen.

wet species, such as Fraxinus (ash) and Juglans (walnut). The seed profiles show a gradual change to drier conditions about 400 years ago, coinciding with the trend in core DC-3.

Leipsic River Core LR-1

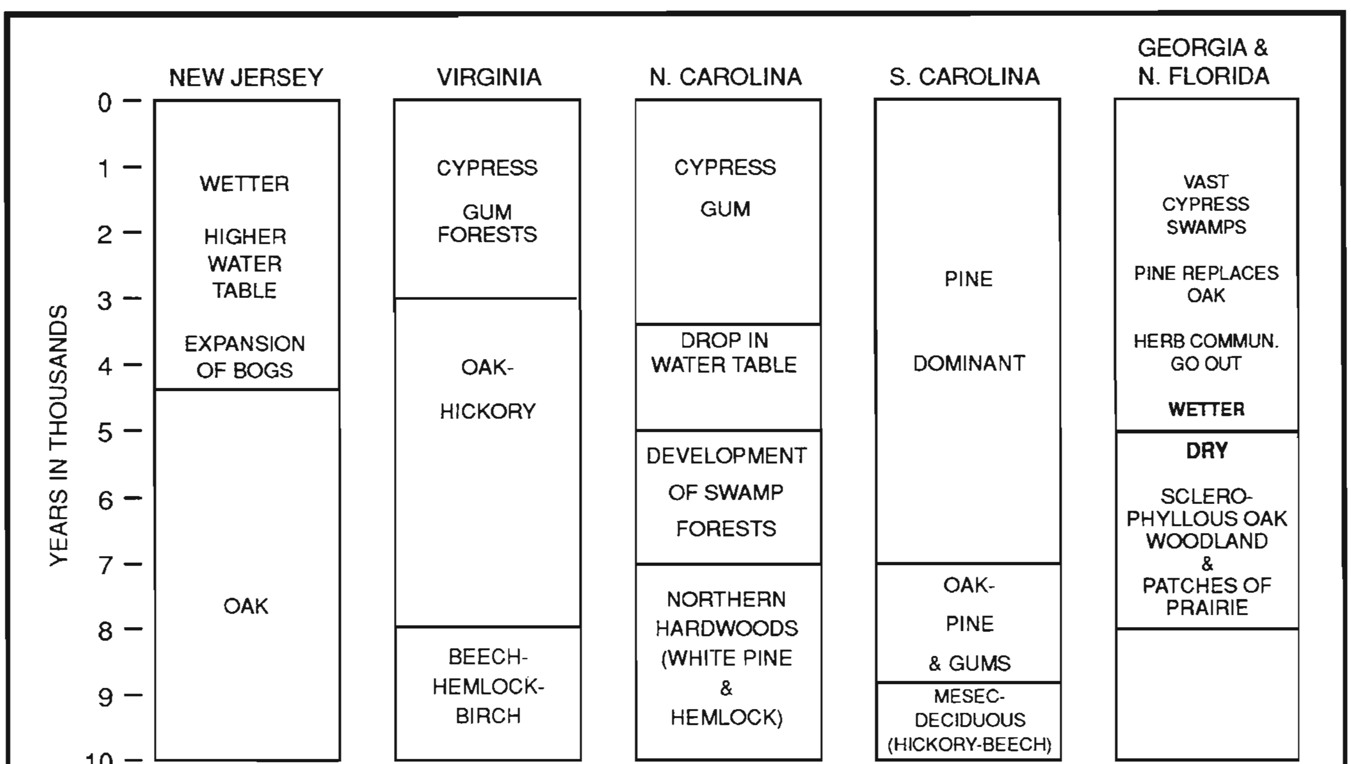
This core has a relatively low sedimentation rate (180 cm in 6200 years). Preservation was not as good as in cores DC-3 or SJ-3. The core was not analyzed for seeds or charcoal.

Sedimentation Rates (Figure 57). Sedimentation rates are very low in this core, ranging from 0.02 to 0.12 cm/yr, and show little fluctuation.

Pollen (Figure 57 and Appendix VI). The bottom portion of the core extending in time from 6000 to 5000 years ago contains some sand and no pollen. For a period of 2000 years from 5000 to 3000 years ago, Pinus (pine) is important, Solidago (goldenrod) is present part of the time and Pteridium (bracken fern) for the entire period, when it drops out. Following this period, there is a short interval of 500 years when Zizania (wild rice) is important briefly, followed by Quercus (oak) and Gramineae (grasses). Then for about 300 years, oak decreases, Rumex (dock) and wild rice are important, and this is followed by another period of a few centuries when oak increases abruptly again accompanied by grasses which continue to increase thereafter. There are very few fluctuations in the profiles during the last 1800 years, with the exception of a period just prior to European settlement when no pollen was deposited or preserved. After

FIGURE 58

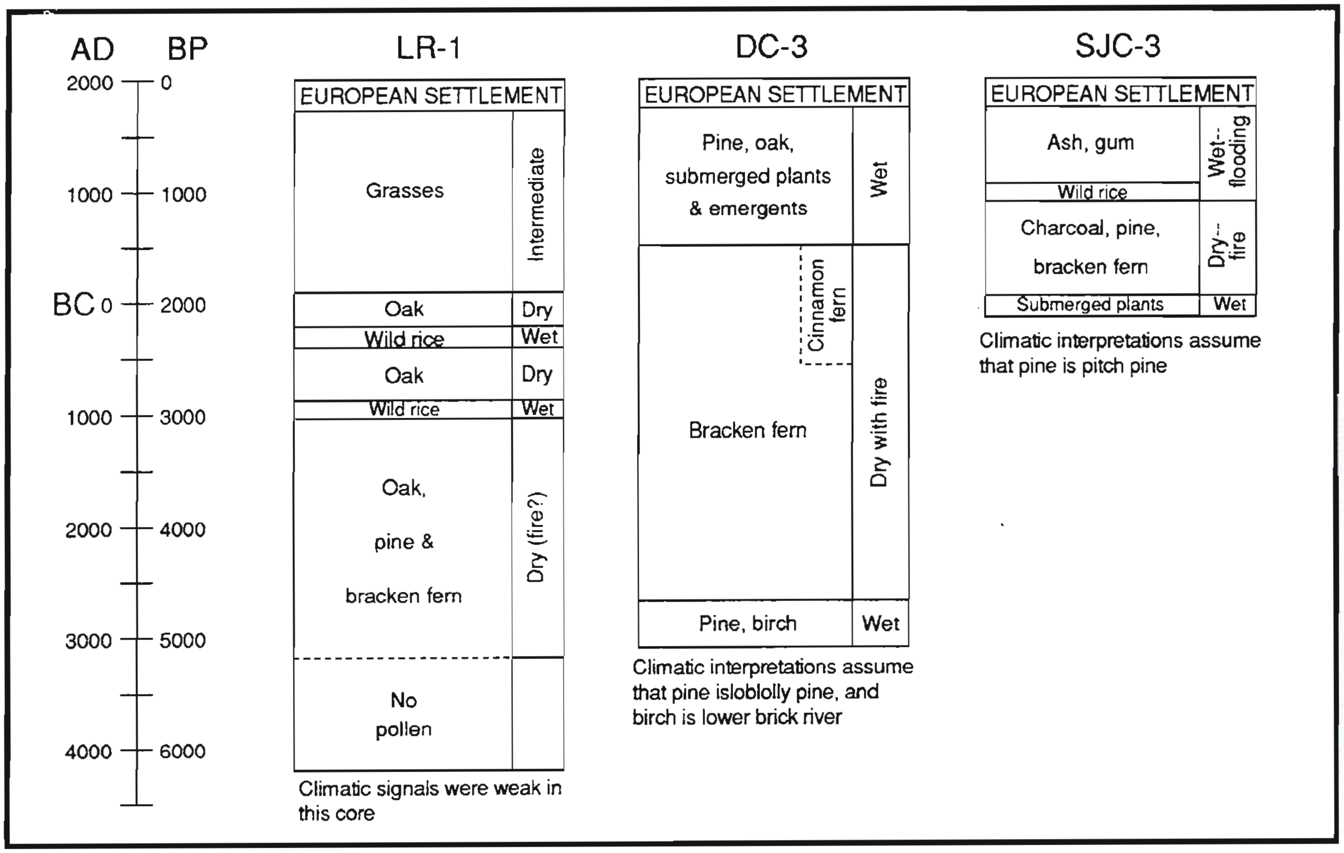
Regional Vegetation Correlation Chart



Summary of Holocene vegetation in the eastern United States south of the maximum extent of the last glaciation.

FIGURE 59

Summary of Vegetation and Climate



European settlement, most pollen types increase initially. This is followed by a decrease in the dominant species, with the exception of pine which reaches its greatest abundance in the last century.

Interpretation of Core LR-1

The most dramatic change in this core is registered between 3000 and 1800 years ago, where for a period of 1200 years, there are major oscillations between what appear to be dry and wet conditions. Prior to 3000 years ago, the flora suggests a landscape characterized by dry ground, with at least intermittent fires. This was followed by a century of wet conditions (wild rice); then 200 to 300 years of dry conditions (oak and grasses), 100 to 200 years wet (wild rice), and then another 300 to 400 dry years. Conditions appear to have remained dry until the present, or at least drier than at the other study localities. However, the preservation in this core and the low resolution do not allow for definitive climatic interpretations.

DISCUSSION AND CONCLUSIONS

Pollen and seed profiles from the Atlantic coastal region of the USA south of the glacial border show the development and expansion of cypress-gum forests from 5000 to 3000 years ago (Watts 1979, 1980; Whitehead 1981, Colquohn and Brooks 1987) (Figure 58). Except for deterioration due to deforestation and siltation since European settlement, these forests still characterize much of the region.

TABLE 12

Vegetation and Climate Inferred from the Pollen Cores

		Total Taxa	------- Non-Tree Taxa ------- % Taxa	% Influx	Diversity		
EUROPEAN COLONIZATION							
	1980's - Mid 1800's	20	36	21	0.92		350 years
1	Mid 1800's - Mid 1700's	23	45	21	1.48		
	Mid 1700's - Mid 1600's	20	52	21	1.45	Deforestation	
WET- DRY							
	1650 - 1500	20	38	14	1.14	150 years - Drier	775 years
2	1500 - 950	21	43	17	1.22	550 years - Wet	
	950 - 875	14	36	11	0.55	75 years - Extremely wet (flooding)	
DRY- WET							
3	875 - 550	23	45	11	1.27	325 years - Less dry	775 years
	550 - 100	22	44	12	1.17	450 years - Extremely dry (fires)	
WET- DRY							
4	? - A.D.100	Sequence of seeds similiar to **2**					
(Based on Date from CoreSJ-3)							

Except for Clark's (1986) study of barrier islands off Long Island, few studies show the kind of temporal variation that occurs within the longer time frame of millennia. The cores from Delaware provide information with respect to shorter term oscillations. A summary of these cores (Figure 59) shows a complex spatial and temporal pattern of dry periods, sometimes (or maybe always) characterized by fire alternating with wet periods, including periods of inundation. The variability of the water table can be influenced by sea level change. However, the changes must be influenced indirectly if not directly by climate, because similar oscillations have been identified in cores from New Jersey and Maryland (Brush, Hinnov, and Thornton, unpublished data). One could hypothesize that extensive fires through the Coastal Plain would eventually provide enough exotic materials into the atmosphere to provide nucleation conditions for cloud formation, with a feedback of high precipitation resulting initially in much of the landscape being inundated. Although the existing cores suggest such a scenario, a much larger and more intensive sampling procedure is required to test the hypothesis.

A comparison of the major oscillations in cores SJ-3 and DC-3 with the $\delta^{18}O$ oscillations in the ice core (Figure 55) shows good correspondence. Although the record for SJ-3 is fairly short, the period prior to 2000 years ago was wet according to the seed record. This corresponds with the colder interval of 3000 to 2000 years ago in the ice core. The period of intensive fires, and presumably dry conditions from 2000 to 1000 years ago corresponds with a warm interval of 1000 years in the ice core. This was followed by very wet to wet conditions in both cores SJ-3 and DC-3, corresponding with cooler conditions in the ice core. Within these 1000 year intervals there are oscillations in the ice core, and also in sediment cores where the resolution is high.

The effect of these climatic events registered in the flora would have a profound influence on the landscape. The most immediate effect is a change in the water table, but fire also denudes the landscape of vegetation and allows for soil erosion and subsequent sedimentation and turbidity of aquatic systems. Total taxa, percent of arboreal and non-arboreal taxa, and the diversity of the non-arboreal taxa show that the lowest number and diversity of taxa of shrubs and herbaceous plants occurred at the end of the dry period 1000 years ago (Table 12). This period was followed by approximately 75 years of flooding and inundation of much of the landscape, when few habitats were available for land plants. The diversity was highest during the subsequent interval as the land became drier, producing a variety of both wet and dry habitats. Although the number of taxa did not change significantly as conditions became still drier, diversity decreased, indicating a loss of wet habitats. Diversity was highest during initial and developing agriculture, although again a number of taxa did not change. The high diversity is probably due to the opening of numerous gaps with initial deforestation, allowing for the growth of shade-intolerant species and also the migration of other species into new areas. However, with the change to mechanized agriculture and a deep plow zone, diversity decreased to the lowest at any time. From the beginning of European agriculture, the number of non-arboreal taxa underwent a steady decline.

INTEGRATION AND INTERPRETATION: PREHISTORIC ENVIRONMENTS OF EASTERN DELAWARE

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GENERAL SUMMARY AND REVIEW

The two other studies explore the history of wetlands adjacent to large, important archaeological sites in the State Route 1 corridor. The river-valley peat deposits are the remains of past wetlands. The pollen, plant fragments, and seeds preserved in the peat deposits record the ancient plant communities in the area. The sand, silt, and clay material deposited by the rivers over the centuries show changes in river flow and wetland development. The wetlands have also recorded the impacts of rising sea level on the river systems. The study of Rogers and Pizzuto (in this volume) developed a new technique (LOI analysis) that allowed for more detailed interpretation of past wetland environments than had previously been possible. Brush (in this volume) studied the pollen and plant macrofossils in the wetland cores of Rogers and Pizzuto to show how the plant communities changed through time. The fossil pollen shows what types of plants were growing on the wetlands in the past, but also reflects the impacts of climate changes on the forests of the region.

Bay/Basins and Regional Climate

Newby, Webb, and Webb (in this volume) used pollen and sediment analyses of Walter's Puddle, a small "bay/basin" pond, to document changes in vegetation and climate in central Delaware. During the last ice age, spruce and fir trees grew in Delaware under a cold, wet climate. Melting of the ice sheet brought warmer and drier conditions to the region. The environment became so dry that after 12,000 BP Walter's Puddle dried up completely. No mud or pollen was deposited in the pond until after 6000 BP when water again stood in the depression. Because the dryness caused a gap in the accumulation of mud in the lake there is not a record of the environments between 12,000 and 6000 BP at Walter's Puddle.

After 6000 BP the climate of central Delaware was wetter and mud and pollen accumulated in Walter's Puddle again. A mixed forest of oak, pine, and hickory trees grew in the region. Buttonbush, alder, sedges, and other wetland plants grew around the pond. Only six pollen samples were taken from the mud above the gap in the Walter's Puddle core; therefore, subtle changes in vegetation and climate over the past 6000 years cannot be discerned. Also a slow sedimentation rate (0.01 cm/yr) combined with mixing of the sediments by currents, worms, or plant roots tend to average out variations in pollen through time (for example see, Davis 1974). In general, the pollen sequence from Walter's Puddle agrees with sequences summarized in regional overviews (for example, Gaudreau 1988; Delcourt and Delcourt 1987a).

From the initial Walter's Puddle study it was impossible to tell when the dry interval before 6000 BP began. Mud that accumulated after 12,000 BP may have been eroded by the action of winds. The actual length of the dry interval is also difficult to determine for the same reason. Dryness could have lasted 6000 years or perhaps only 100 years. Furthermore, the gap in mud accumulation might have been caused by hydrological changes unique to Walter's Puddle. Therefore, the second study in this volume by Webb, Newby, and Webb was undertaken.

Webb, Newby, and Webb (in this volume) used transects of cores across four bay/basins, including additional cores from Walter's Puddle, to determine if the dry interval at Walter's Puddle was due to climate, and to determine the length of the dry interval. All four basins had a gap in sedimentation, therefore, local hydrological conditions can be ruled out as the cause for the lower water levels. In three of the cores drying cracks were found below the gap in sedimentation. Regional climate change was responsible for lower water levels in all four ponds. Either precipitation decreased and/or temperature increased. In this case, both factors were responsible. The wetter climate before 12,000 BP was due, in part, to the cold air associated with the ice sheet margin close by in southern New York state (see Figure 10). As the ice sheet withdrew, precipitation moved north of the Delmarva region into Canada. In addition, the orbit of the earth around the sun had reached a position that increased solar heating of the earth (see Figure 9).

The beginning of the dry interval is probably about 11,000 BP because radiocarbon dates from just below the gap in all four ponds agree. Such consistent radiocarbon dates would not be expected if dried lake bottom mud had been eroded from the basins. The dates for the end of dry conditions are less susceptible to error, and are also consistent between the ponds. The basins filled with water again after 6000 BP. From 6000 BP to the present water levels in the basins have remained relatively high, and no significant gaps in sedimentation are evident. The radiocarbon date from Prison Pond above the gap does not agree with the dates from the three other ponds. Prison Pond is shallower than the other ponds and may have been sensitive to other dry intervals in the last 6000 years that did not affect mud deposition in the other deeper ponds.

Wet and dry are relative terms. We cannot determine the amount of precipitation that fell during the last 6000 years because the pollen data do not tell us the exact types of trees that grew on the landscape. Therefore, we cannot use modern ecological information on the known moisture and temperature requirements of, for example, red oak, to estimate past conditions. Thus, wetter conditions after 6000 BP, may still have been dry compared with the present climate of Delaware. The archaeological sites that date from the Woodland I time period found buried under wind-blown silts and sands (Curry and Custer 1982; Custer and Watson 1987; Ward and Bachman 1987) are evidence of the relative dryness of the climate in Delaware during the last 6000 years.

Riverine Marshes: Local Environments and Sea-Level Rise

The third study in this volume, by Rogers and Pizzuto, shows how three river systems developed and how wetlands grew to fill the valleys as sea level rose. The oldest sediments encountered were almost 12,000 years old, but most of the wetlands were younger. Each stream valley under went a slightly different sequence of development, but in general, their evolutions followed the same pattern. Fresh water wetlands existed in the Duck Creek river valley 11,500 years ago, and in the Leipsic River valley 8000 years ago. As the river channels shifted, wetlands expanded or contracted. When sea level reached high enough, some fresh water was pushed back up the streams by tidal action. Sediments then began to accumulate more rapidly and mudflats developed. Slowly tidal action became more significant and water levels increased. Ultimately salt water intruded into the rivers and vegetation in the wetlands began to be affected. The process is continuing and estuarine conditions will move upstream and salt marshes will develop and expand.

The study shows that wetlands existed in the river valleys that emptied into the Delaware River throughout the last 10,000 years. These wetlands would have been sources of fresh water and probably edible plant foods. They also would have attracted game animals. Thus, these environments attracted people as well. It is not clear how the dry period documented in the first two studies impacted these riverine wetlands.

The pollen studies by Brush (in this volume) were on cores dating to the last 5000 years - after the dry episode documented by study of the bay/basins. The oldest vegetation data in the marsh cores comes from pollen in Leipsic River core LR-1 and dates to about 5000 BP. As suggested by the pollen from Walter's Puddle, oak and pine forests dominated the landscapes at the time. However, continued dryness is indicated by fire-adapted vegetation such as bracken fern. More detail on the vegetation and climate of the last 5000 years was found in the three marsh cores studied than for the bay/basins. Many more samples, closely spaced in time, yield a higher resolution record of past environments.

The marsh pollen data suggest a wetter (and perhaps colder) interval sometime between 3000 and 2000 BP. Another dry interval followed. These changes correspond roughly with large-scale, climatic changes recorded in Greenland ice cores. The marsh cores, therefore, give regional information on climate and vegetation as well as local data that reinforce and corroborate the wetland interpretations of Rogers and Pizzuto.

TECHNICAL COMMENTS AND IMPLICATIONS FOR PREHISTORIC ARCHAEOLOGY

The data on prehistoric environments provided by the studies in this volume refine our understanding of prehistoric human occupation in the region. Modern environments in the study area are not good analogs for past environments. The climatic conditions and resources available to people in the past profoundly influenced their lives. Environments thousands of years ago were very different from the present. About 12,000 years ago the climate of Delaware was probably more like that of eastern Maine - cold and wet. However, there is no exact modern analog for the environments of the time because conifer trees of the boreal forest were mixed with more southerly broadleaf tree species (Delcourt and Delcourt 1987a; Gaudreau 1988; Jacobson, Webb, and Grimm 1987). The animals living in the area probably included extinct species like the mastodon, as well as, caribou, elk, and moose, but like the vegetation, a mixture of northern and southern animal species was present (see Graham and Mead 1987).

Paleo-Indian period life styles have been characterized as seasonal wandering following herds of large game animals (Gardner 1977:258-259, 1979; Custer, Cavallo, and Stewart 1983). Finds at the Shawnee-Minisink Paleo-Indian site, however, reveal that Paleo-Indians used a variety of plant resources also (McNett, McMillian, and Marshall 1977). In northern Delaware there is an association between interior swamps and Paleo-Indian sites and outcrops of high quality stone raw materials (Custer and Bachman 1986). The bay/basin ponds and wetlands were probably important watering holes for game animals. People would have camped nearby while hunting. The importance of such water holes probably increased after 11,000 BP as the climate became dryer until finally many of the small, shallow ponds dried up. Any ponds that remained were probably very important fresh water sources.

Archaeological sites dating to the time before about 6500 years ago are relatively rare in Delaware. Perhaps, the scarcity of fresh water made the area inhospitable. Settlements dating to the Archaic period are found near reliable fresh water sources. Even if there were some bay/basins and free-flowing streams in Delaware, they may have been unpredictable, or only seasonal fresh water sources. Perhaps, evidence

PLATE 8

Archaeological Field Work at the Pollock Site

of human occupation is sparse because few people ventured onto what may have been the "Delmarva desert".

After 6500 BP settlement around bay/basin features was common (Custer and Bachman 1986). Bay/basins apparently attracted people when they held water during wetter climate intervals. In Woodland II times bay/basins use declined, perhaps in response to the introduction of agriculture or increase in the use of coastal resources such as shellfish. The climate during the Woodland II was closer to the modern, relatively moist climate; therefore, access to fresh water was a less important consideration in selecting a campsite or village location.

The shift to the use of coastal resources coincides with the rise of sea level to its present elevation (Custer 1988). The infilling of river valleys that had been cut down to lower sea levels is documented by Rogers and Pizzuto (in this volume). The stabilization of sea level allowed the development of more extensive coastal estuaries and wetlands (Braun 1974; Custer 1988; Perlman 1980). Prehistoric settlement near the limit of tidal influence along a stream allowed access to a wide variety of food resources from interior forests, freshwater river and wetlands, and brackish and salt water estuary environments.

Archaeology of the State Route 1 Corridor: Preliminary Results

Fifty-five prehistoric archaeological sites ranging in age from 8500 to 400 BP were located in surveys of the State Route 1 corridor (Bachman, Grettler, and Custer 1988). Seventeen archaeological sites were investigated more intensively (Riley et al. 1993). Large scale excavations were undertaken at intensively occupied areas near the Leipsic River coring locality and also near the St. Jones River coring locality during 1990 and 1991 (Plate 8). Analysis of the archaeological findings is underway; only preliminary results are available.

Walter's Puddle. Walter's Puddle (Basin B) is located in the Blackbird study area, a large area surveyed for prehistoric archaeological sites early in the State Route 1 project (Custer and Bachman 1986a, 1986b). Ninety percent of 148 tested localities within 50 m of a bay/basin had evidence of prehistoric occupation. In Delaware there is little evidence of bay/basin use during the Paleo-Indian period (Custer and Bachman 1986b:5; Custer 1989:107). The earliest evidence of prehistoric bay/basins use in Delaware dates to about 8500 BP (Custer and Bachman 1986b:5). The studies presented in this volume suggest that this was the time of maximum dryness in the early Holocene. Many bay/basins did not hold water year round, but may have been seasonally wet. Within a generally dry environment, bay/basins would have been important fresh water sources. Archaeological sites dating to around 8500 BP are small, ephemeral hunting camps (Custer and Bachman 1986b:5). The archaeological evidence suggests short-term occupations of campsites while small groups of people moved around the landscape hunting and gathering wild foods.

Bay/basin use increased during the Woodland I period, but by the Woodland II period bay/basin use was rare. Climatic fluctuations during the last 5000 years are difficult to discern from the bay/basin pollen data; however, fresh water was apparently more widespread, in general, as the climate of eastern North America gradually cooled over the last 4000 years. Another factor was the development of coastal environments. By 6000 BP the rate of sea-level rise, due to the melting of the ice sheets, had slowed and by 4000 BP sea level had reached a level close to its present elevation. Biologically productive salt marshes and estuaries then expanded creating new opportunities for prehistoric people living on the Delmarva Peninsula (Custer 1988). The studies by Rogers and Pizzuto and by Brush (in this volume) document how these processes took place.

Duck Creek. Near the spot where Rogers and Pizzuto cored in the Smyrna River, five small archaeological sites were tested during the State Route 1 archaeological research (Riley et al. 1993). Most of the occupations date to the Woodland period, but evidence of earlier occupation was found at site 7NC-J-134. Unfortunately the site had been plowed and undergone extensive soil erosion (Riley et al. 1993). The coring of Duck Creek showed that wetland environments had been present throughout the past 11,000 years in the river valley.

Pollen data from core DC-3 date as far back as 5700 BP. The basal dates for this core are problematic because an older date was obtained above a younger date. Some redeposition of sediments eroded from the landscape following the earlier dry interval documented in the bay/basin studies may be responsible. If redeposition occurred then sedimentation rates calculated from pollen concentrations could be in error. This affects the pollen influx values presented by Brush (in this volume). Nonetheless, the pollen evidence agrees with the regional record largely indicating oak/hickory forests with some pines. The pines are either few in number relative to oaks and hickories, or are some distance from the core location because pines are much more prolific pollen producers than other trees and their pollen grains can be spread widely by wind.

Significant changes in the calculated pollen influxes coincide with changes in the geology of the core, so the environment of deposition must be considered in interpreting the data. For example, the influx in alder pollen appears to be related to shifts from forested wetland to emergent wetland and back to forested conditions. Birch pollen influx follows the same pattern suggesting a change from forested swamp to marsh and back to swamp at the core locality. Given such changes in the geology, and the local nature of the pollen record that accompanies such changes it is very difficult to extract regional climate information from the marsh core. The peat may represent a dryer interval of time when water levels dropped somewhat and the location was not inundated as frequently. Later a swamp environment developed, but this was due in part to sea-level rise. Rogers and Pizzuto (in this volume) place tidal influence in the later part of the peat unit.

Since about 1400 BP the location of core DC-3 was dominated by shrub and forest swamps adjacent to the stream channel, while mudflats occurred on the opposite side of the stream. As water deepened with sea-level rise the swamp forest was replaced by mudflats with emergent herbaceous vegetation. Now, brackish mudflat and emergent marsh cover the whole stream valley.

For people living nearby, the shifts in local wetland conditions were probably a minor consideration because the sea-level transgression shifted the environments slightly landward (upstream) through time. Thus, the same types of wetland environments were available regionally, even if certain patches changed in character and biological productivity. The important characteristic of these wetlands for human occupation was their ecological diversity. This diversity can be seen in comparisons between the three pollen diagrams from the three different stream/wetland systems. Thus, the Woodland period occupants of the area had access to a wide variety of environments, and presumably food sources and game habitats, throughout the period. Small procurement campsites of the Woodland I time period gave way to larger more sedentary settlements in the Woodland II suggesting that food resources were reliable and predictable.

Leipsic River. For most of the past 8000 years, wooded swamp grew along the Leipsic River where it will be crossed by State Route 1. Preservation was poor in core LR-1 - pollen was not found below 140 cm in the core and two other intervals of no pollen accumulation (or preservation) occur higher in the core. Alders and birches dominate the local vegetation, but wild rice grew during two times about 3000 BP and again at 2000 BP. Grass pollen influx was high, but fluctuated, from around 2500 BP until the present. The LOI values measured by Rogers and Pizzuto suggest forested swamp deposits during this time, but marsh is suggested by the pollen.

Seeds and charcoal were not analyzed in the Leipsic River core because of the preservation problems. The large fluctuations in pollen influxes suggest that local processes of vegetation change dominate the data here. The reconstruction of Rogers and Pizzuto places the arrival of tidal influence here at 500 BP. Thus, prehistoric occupants of the area had access to wooded swamps adjacent to the Leipsic River throughout the last 5000 years. Localized populations of herbaceous plants including grasses and wild rice would have provided edible wild foods.

Prehistoric occupation in the Leipsic area was extensive and intensive (Riley et al. 1993). Prehistoric archaeological sites line both sides of the Leipsic River. On the north side of the river is the Leipsic site complex with evidence of occupation throughout the Woodland periods. There appears to be less intensive use of the sites between 2000 and 1000 BP. Semi-subterranean house pits and underground storage pits (Plate 9) were abundant from 3000 to 2000 BP and after 1000 BP. Oak, charcoal and charred hickory nuts are among the floral remains recovered from prehistoric pits, hearths, and houses (Riley et al. 1993).

PLATE 9

Excavating a Prehistoric Feature

On the south side of the river is the Pollock site complex with evidence of occupation and use from late Paleo-Indian times through the Woodland II period. The most intensive use of the sites was during the Woodland I period. House and storage pits are common. Preliminary data suggest, at least, fall occupation based on the presence of charred hickory nut hulls from prehistoric features. More complete information will be available after the analysis of flotation samples (Plates 10 and 11) from 350 features at the Leipsic sites and over 1100 from the Pollack sites (Grettler, personal communication). Pizzuto and co-workers have taken more cores from the Leipsic River and these are currently under study. Integration of the environmental and archaeological studies will be possible when all of the analyses are completed. The combination of detailed environmental data and large scale archaeological excavations promises many new insights into prehistoric life in Delaware.

St. Jones River. The paleoenvironments of the St. Jones River area are complicated by the fact that the stream meandered and changed its course through time. The core analyzed for pollen came from a meander cut-off channel that dates to after 2000 BP. Again large changes in pollen deposition coincide with geological changes in the core. Prior to about 1000 BP the cut-off channel accumulated pollen in muddy deposits probably in relatively shallow water with alders and river birch. Open water is indicated by water lilies and other aquatic species. Wild rice is abundant just before 1000 BP. The regional pollen signal again reflects the dominance of oak, hickory, and pine trees. After 1000 BP the pollen influx decreases significantly. This change coincides with the transition from open water to marsh as the channel filled with sediment.

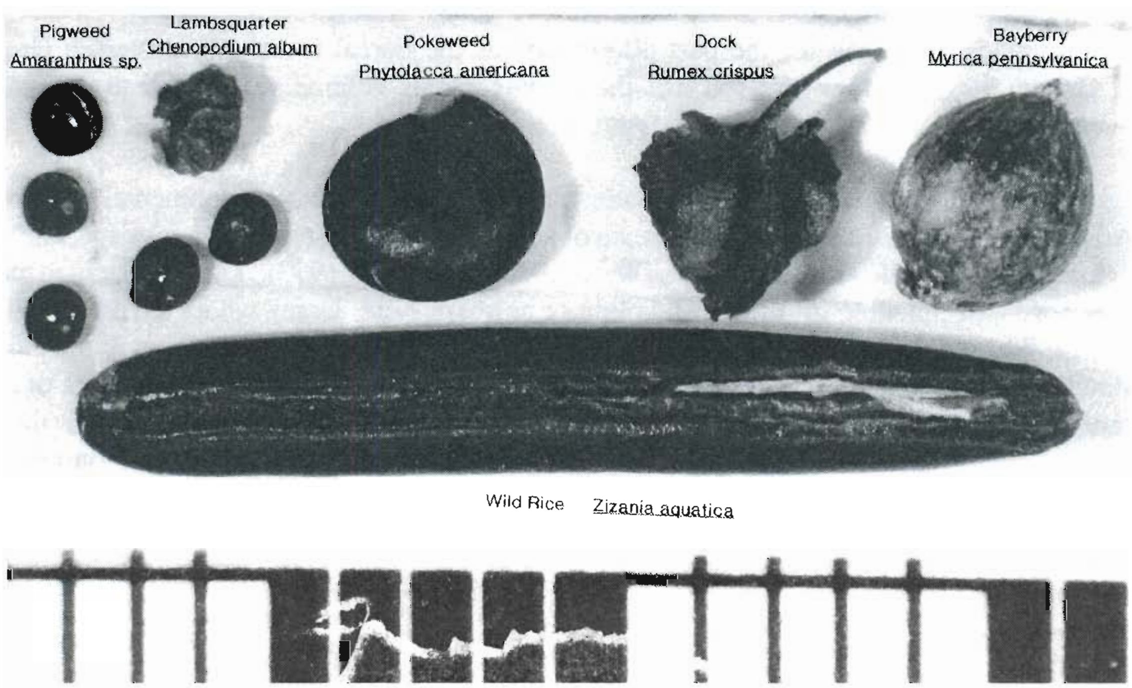
Active and abandoned channels provide the most diverse wetland habitats of the four areas studied. Both flowing and standing water environments were present. The cut-off of the meander channel may coincide with increased river flow, but other cut-offs would have to be dated to demonstrate a regional

PLATE 10

Flotation of Feature Fill to Recover Plant Fragments and Seeds

PLATE 11

Plant Fragments and Seeds Recovered from a Feature



pattern. Dryer local conditions after 1000 BP are suggested by the build up of sediment and peat to the top of the contemporaneous water table in the cut-off channel core.

Intensive occupation of the area adjacent to the core locations occurred during the Woodland period, most intensively during the Woodland I at the Carey Farm and Island Fields sites. Evidence of use of the area dates to the late Paleo-Indian period and extends to the Late Woodland II (Watson, personal communication). Brush notes large influxes of charcoal that suggests fires in the region; perhaps, the cooking fires and clearance activities of the prehistoric inhabitants of the area are reflected rather than a dry climate. Flotation samples from over 1200 prehistoric features are in analysis (Watson, personal communication). Pizzuto and co-workers are currently studying other cores from the St. Jones River adjacent to the prehistoric occupations. The studies of prehistoric occupations along the St. Jones and the Leipsic rivers will be the most detailed in the region and will provide a new benchmark for comparisons throughout the mid-Atlantic.

CONCLUSIONS

The studies reported here have substantially added to our knowledge of past environments. The studies of the bay/basin features have clearly shown that the early Holocene of the Delmarva Peninsula was warm and dry. The dry period is contemporaneous with the extension of the "prairie peninsula" (Delcourt and Delcourt 1987a:98; Jacobson, Webb, and Grimm 1987; Gaudreau 1988) and the maximum of solar warmth at about 9000 BP (Kutzbach 1987).

The four pollen records presented here agree on the broad outlines of the regional vegetation and, by inference, climate. Subtle changes during the last 5000 years are difficult to resolve. Changing conditions in the riverine wetlands suggest changes in water flow; however, dynamic responses to sea-level rise are also responsible for changes in the geology of the cores. Paleoenvironmental studies have focused on the dramatic changes at the end of the last ice age, and more subtle changes in Holocene vegetation and climate have been neglected. Some studies (for example, Denton and Karlen 1973) suggest a 2500 year cycle of temperature fluctuation that is responsible for "Neoglaciations" including the "Little Ice Age" documented in Europe and other areas of the world (Grove 1988). Studies across northern North America uniformly show gradual cooling for the past 4000 years as the boreal forest has expanded (Jacobson, Webb, and Grimm 1987). More research like the studies in this volume are needed to determine the Holocene vegetation and climate of the mid-Atlantic Region.

The Delmarva Peninsula falls in a climatic transition zone. Paleoenvironmental studies of the southern Atlantic coastal plain show the importance of southern pine forests on the landscape, and cypress trees are significant at the pollen study localities (Watts 1980; Whitehead 1973). The Appalachian mountain chain slashes northeast pinching off the coastal plain in northern New Jersey where ice age glacial scour has transformed the landscape to the north. Elevation affects the climate and vegetation of the mountains and latitudinal changes are evident northward of the Delmarva (Gaudreau 1988). The network of regional pollen diagrams used to reconstruct climate patterns (Delcourt and Delcourt 1984, 1987a) show that a zone of dynamic tension falls across the Middle Atlantic region. Therefore, regional vegetation and climate reconstructions (e.g., Delcourt and Delcourt 1987a; Gaudreau 1988; Watts 1983) are not sensitive to the local conditions on the Delmarva Peninsula.

The importance of the studies in this volume is that they provide the local data that archaeologists need to interpret past lifeways at particular places and specific archaeological sites. The environments reconstructed were the ones that people came into contact with in their daily lives, rather than those created by abstractions and extensions of data and information from other areas and developed for other purposes. The studies in this volume complement the archaeological studies of the State Route 1 corridor, and contribute to our knowledge of Delaware's past by showing how environments changed and developed in the past.

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APPENDICES

APPENDIX I

WALTER'S PUDDLE ARBOREAL POLLEN PERCENTAGES

Level	Pollen Depth	Sample Date(s)	Pi	Ab	Pn	Be	Ts	Fa	Ac	Ul	Fr	Os/C	Qu	Ca	Cs	J/Th	Po
1	0.5	0	0.0	0.0	5.1	0.0	2.0	1.0	0.0	0.0	0.0	0.0	49.0	9.2	0.0	0.0	0.0
2	10.5	1119	0.0	0.0	3.8	0.0	1.0	2.9	0.0	0.0	0.0	0.0	55.2	6.7	0.0	0.0	1.0
3	20.5	2238	0.0	0.0	5.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	64.3	6.3	0.5	0.0	0.0
4	29.5	3245	0.0	0.0	8.2	0.5	1.1	3.3	0.0	0.0	0.0	0.0	53.3	6.0	0.0	0.5	0.0
5	41.5	4588	0.7	0.0	3.3	0.7	0.7	0.7	2.0	0.0	0.0	0.0	58.3	4.0	0.0	0.0	0.0
6	58.5	5820	0.0	0.0	3.9	0.4	0.4	0.4	0.4	0.0	0.0	0.0	50.4	1.7	0.0	0.0	0.0
7	63.5	11880	11.1	0.0	10.1	6.1	1.0	0.0	0.0	0.0	0.0	0.0	29.3	3.0	0.0	0.0	1.0
8	122.5	14986	24.8	0.0	35.6	5.9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
9	150.5	16626	14.4	0.0	43.3	0.0	1.1	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	212.5	20260	9.3	0.0	43.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	254.0	22721	21.1	0.0	32.9	10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

KEY:

Pi = <u>Picea</u> (Spruce)   Ab = Abies (Fir)   Pn = <u>Pinus</u> (Pine)   Be = <u>Betula</u> (Birch)
Fa = <u>Fagus</u> (Beech)   Ac = <u>Acer</u> (Maple)   Ul = Ulmus (Elm)   Fr = Fraxinus (Ash)
Qu = <u>Quercus</u> (Oak)   Ca = <u>Carya</u> (Hickory)   Ts = Tsuga (Hemlock)   Po = <u>Populus</u> (Poplar)
Cs = <u>Castanea</u> (Chestnut)   Os/C = Ostrya/Carpinus (Hazel/Ironwood)
J/Th = <u>Juniperus/Thujus</u> (Juniper/Cedar)

APPENDIX I: Continued

WALTER'S PUDDLE NON-ARBOREAL POLLEN PERCENTAGES

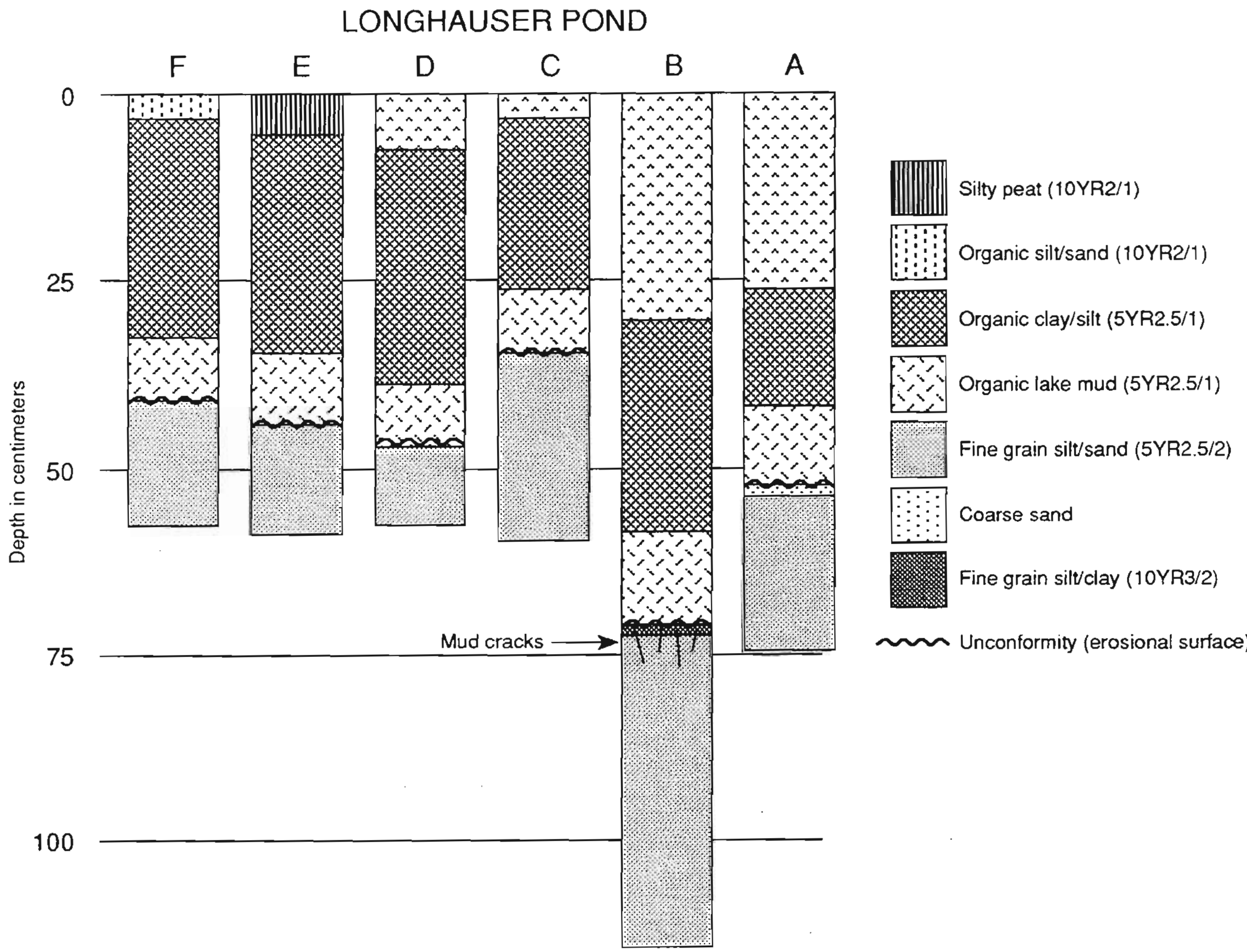
Level	Pollen Depth	Sample Date(s)	Al	Sa	Li	Cy	Gr	Ar	Am	Co	Ce	Ny	My	Th	OtT	OtS	OtH
1	0.5	0	2.0	0.0	0.0	7.1	6.1	0.0	1.0	1.0	14.3	1.0	0.0	0.0	0.0	0.0	1.0
2	10.5	1119	1.9	0.0	2.9	1.0	0.0	0.0	0.0	1.0	21.9	0.0	0.0	1.0	0.0	0.0	0.0
3	20.5	2238	0.9	0.0	1.8	1.8	0.9	0.0	0.0	0.9	14.0	0.0	0.0	0.0	0.0	1.8	0.0
4	29.5	3245	0.5	0.0	2.2	0.5	2.2	0.0	0.0	1.1	18.1	0.0	0.0	2.2	0.0	0.0	0.0
5	41.5	4588	1.3	0.0	4.6	0.0	4.0	0.0	0.7	1.3	17.9	0.0	0.0	0.0	0.0	0.0	0.0
6	58.5	5820	2.2	0.0	3.9	3.0	5.6	0.4	0.4	1.3	24.1	0.4	0.4	0.0	0.4	0.0	0.0
7	63.5	11880	1.0	1.0	1.0	5.1	10.1	0.0	1.0	0.0	18.2	0.0	0.0	0.0	0.0	0.0	1.0
8	122.5	14986	2.0	5.0	0.0	0.0	10.9	1.0	0.0	2.0	0.0	0.0	0.0	1.0	8.9	0.0	0.0
9	150.5	16626	0.0	2.2	2.2	21.1	8.9	1.1	2.2	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0
10	212.5	20260	0.9	0.0	0.0	23.4	6.5	2.8	0.0	1.9	0.0	0.0	0.0	2.8	0.0	0.0	1.9
11	254.0	22721	1.3	1.3	0.0	23.7	5.3	2.6	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0

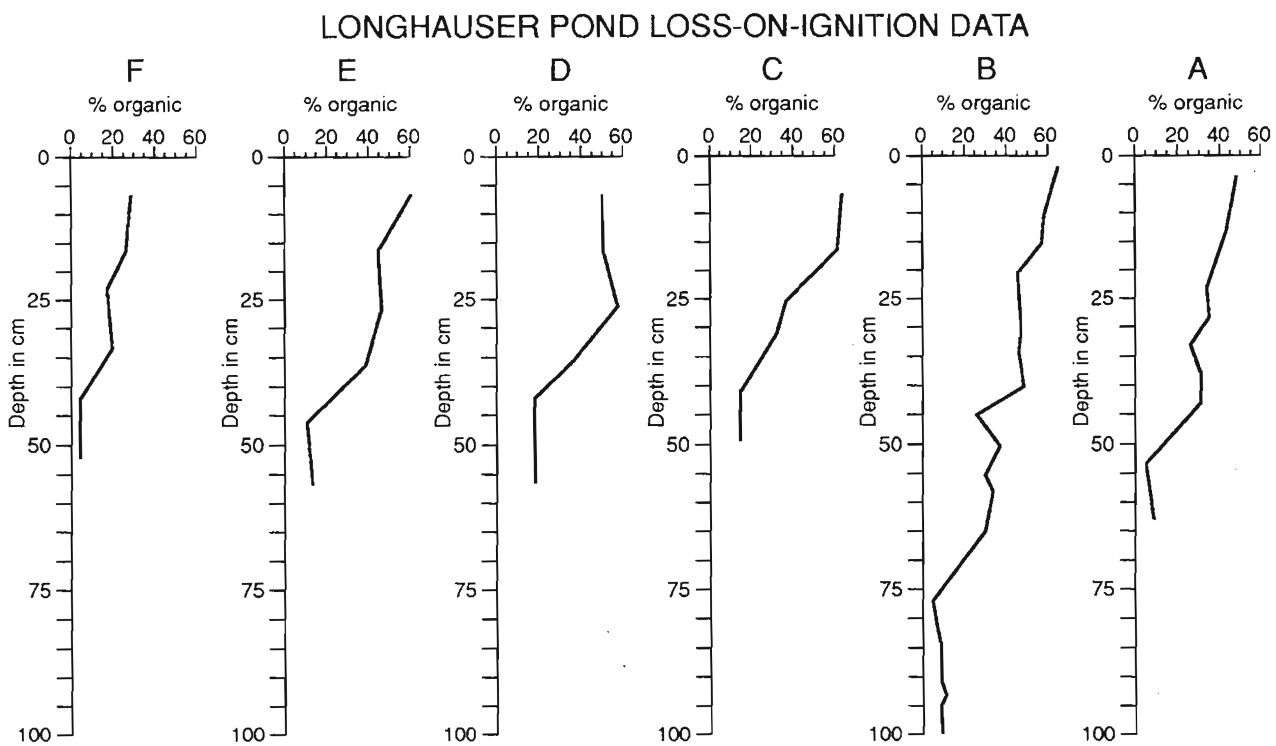
KEY:

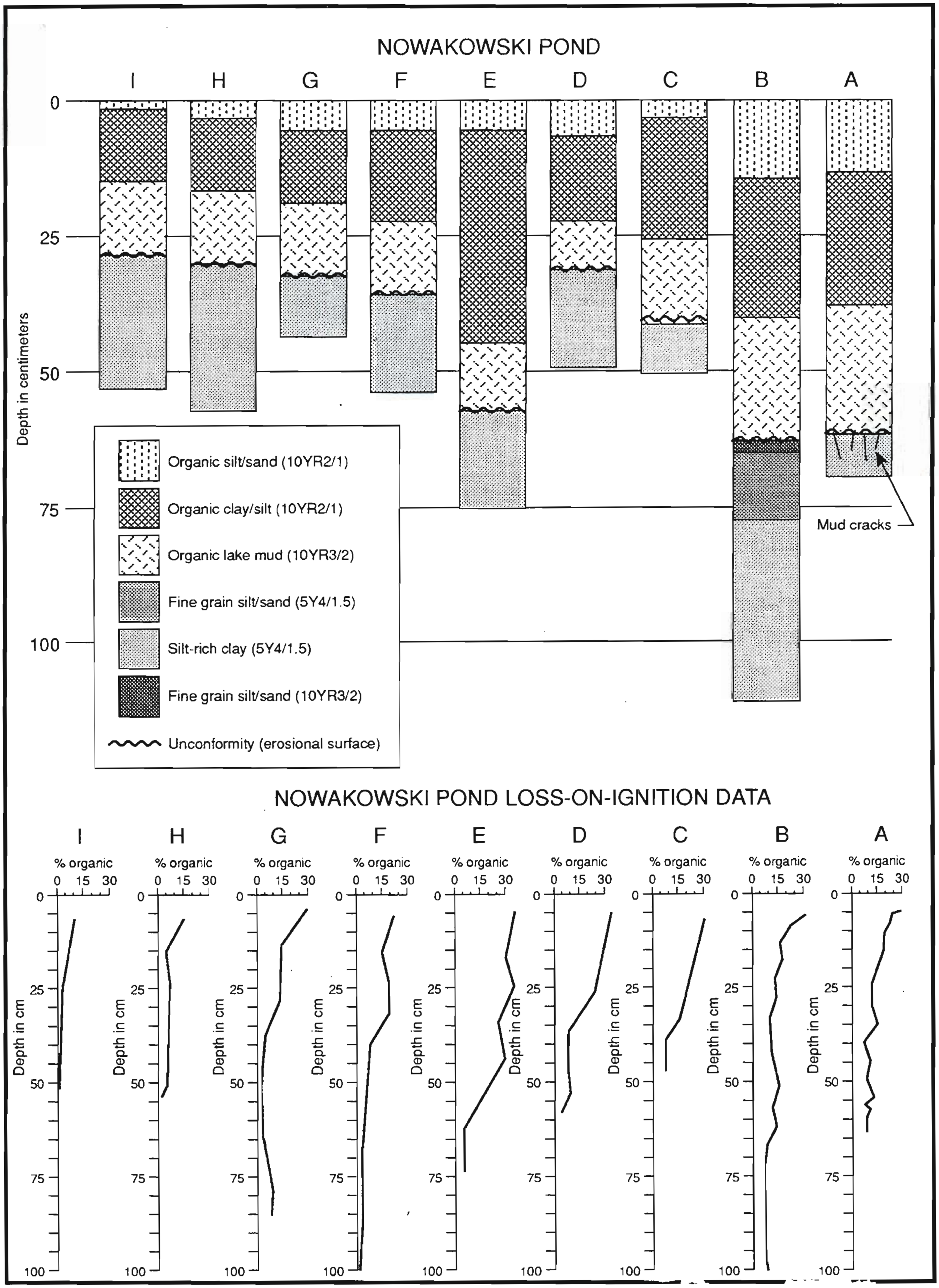
Al = _Alnus_ (Alder) Sa = _Sanguisorba_ (Burnet) Li = _Liquidambar_ (Sweet Gum)
Cy = Cyperaceae (Sedges) Gr = Gramininae (Grasses) Ar = Artemisia (Woorwood)
Am = _Ambrosia_ (Ragweed) Co = Compositae (Composite family) Ny = _Nyssa_ (Tupelo)
Ce = _Cephalanthus_ (Buttonbus) My = _Myrica_ (Wax-Myrtle) Th = _Thalictrum_ (Meadow-Rue)
OtT = Other trees OtS = Other shurbs OtH = Other herbs

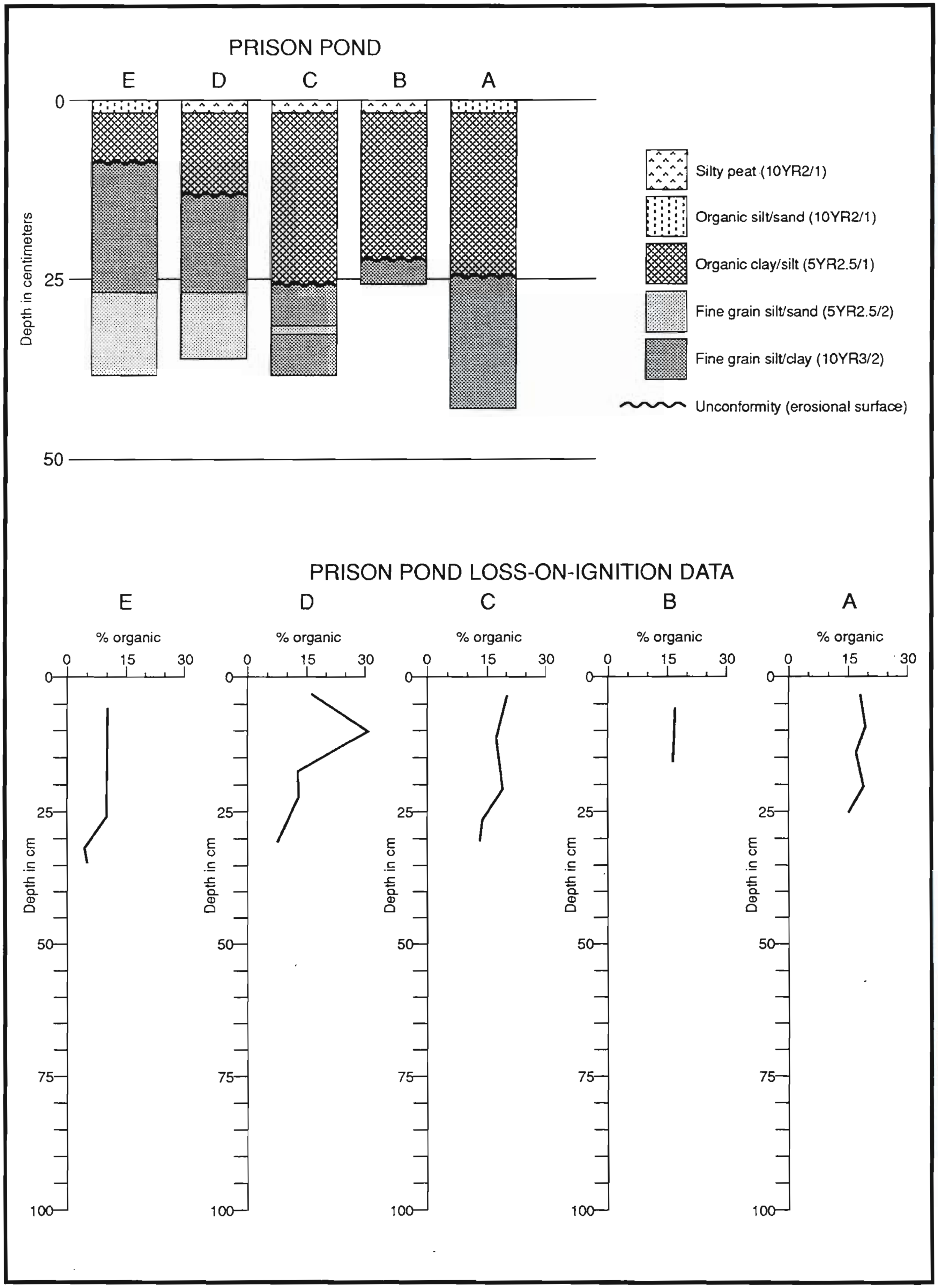
APPENDIX II

Core Diagrams and Loss-On-Ignition Curves for Bay/Basin Study Localities

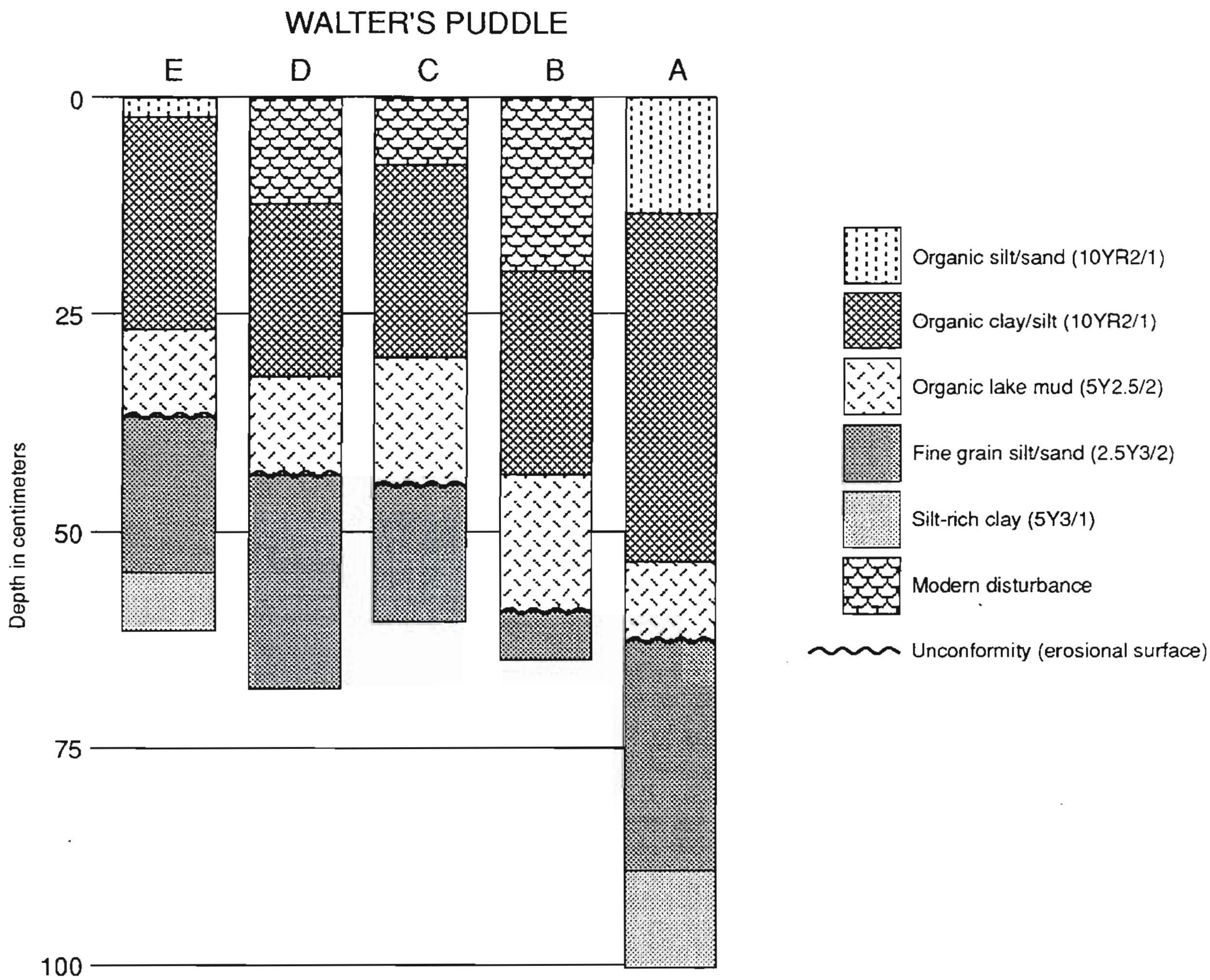

LONGHAUSER POND
F
E
D
C
B
A
0
25
50
75
100
Depth in centimeters
Mud cracks
Silty peat (10YR2/1)
Organic silt/sand (10YR2/1)
Organic clay/silt (5YR2.5/1)
Organic lake mud (5YR2.5/1)
Fine grain silt/sand (5YR2.5/2)
Coarse sand
Fine grain silt/clay (10YR3/2)
Unconformity (erosional surface)

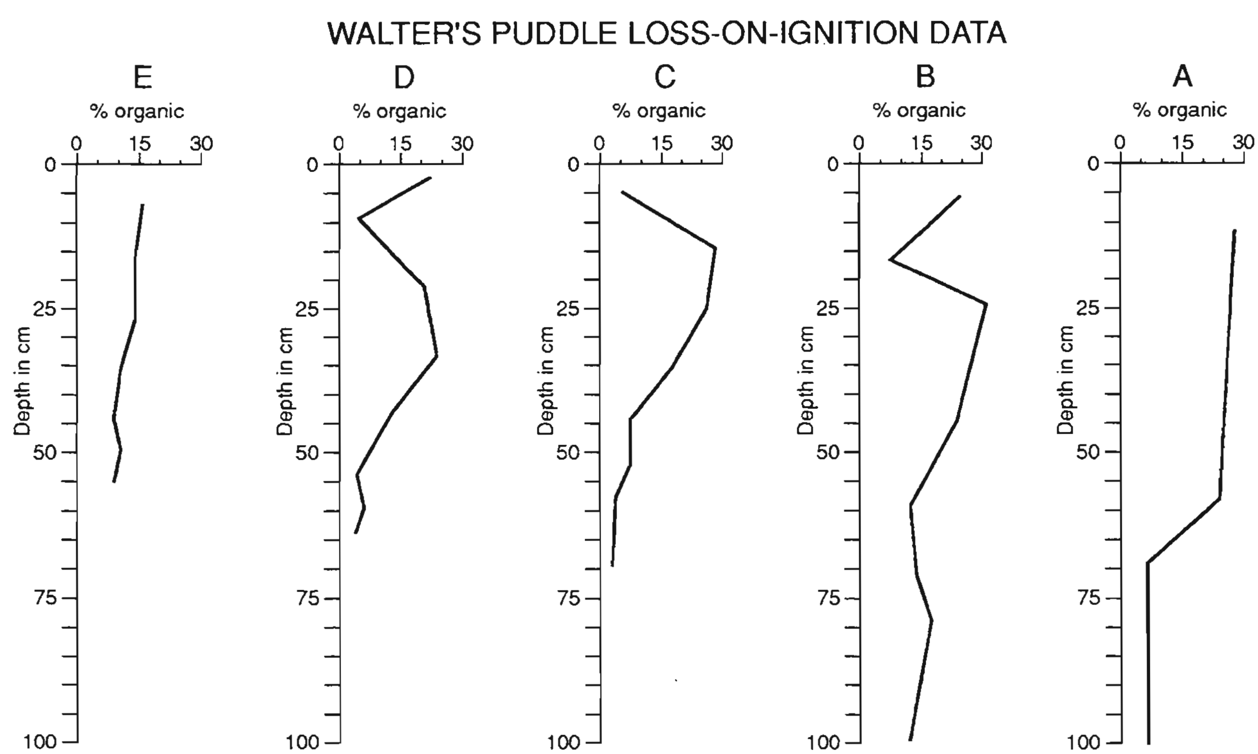

LONGHAUSER POND LOSS-ON-IGNITION DATA
F
E
D
C
B
A
% organic
0 20 40 60
Depth in cm
0
25
50
75
100


NOWAKOWSKI POND
I H G F E D C B A
Depth in centimeters
0
25
50
75
100
Organic silt/sand (10YR2/1)
Organic clay/silt (10YR2/1)
Organic lake mud (10YR3/2)
Fine grain silt/sand (5Y4/1.5)
Silt-rich clay (5Y4/1.5)
Fine grain silt/sand (10YR3/2)
Unconformity (erosional surface)
Mud cracks
NOWAKOWSKI POND LOSS-ON-IGNITION DATA
% organic
0 15 30
Depth in cm



PRISON POND
E D C B A
Depth in centimeters
0
25
50
Silty peat (10YR2/1)
Organic silt/sand (10YR2/1)
Organic clay/silt (5YR2.5/1)
Fine grain silt/sand (5YR2.5/2)
Fine grain silt/clay (10YR3/2)
Unconformity (erosional surface)
PRISON POND LOSS-ON-IGNITION DATA
E D C B A
% organic
0 15 30
Depth in cm
0
25
50
75
100


WALTER'S PUDDLE
E
D
C
B
A
Depth in centimeters
0
25
50
75
100
Organic silt/sand (10YR2/1)
Organic clay/silt (10YR2/1)
Organic lake mud (5Y2.5/2)
Fine grain silt/sand (2.5Y3/2)
Silt-rich clay (5Y3/1)
Modern disturbance
Unconformity (erosional surface)


WALTER'S PUDDLE LOSS-ON-IGNITION DATA
E
D
C
B
A
% organic
0
15
30
Depth in cm
0
25
50
75
100

APPENDIX III

Grain Size Analysis Data for Wetland Cores

Core	Depth (cm)	Mass Sand (g)	Mass Mud (g)	Sand + Mud	% Sand*	Lithology	Environment
TS-4	5.0	0.029	5.369	5.398	0.5	Mud	Channel
TS-4	35.0	0.036	4.190	4.226	0.9	Mud	Channel
SJ-4A	0.1	0.032	2.966	2.998	1.1	Mud	Channel
SJ-4A	20.0	0.058	3.887	3.945	1.5	Mud	Channel
TS-2	20.0	0.081	5.420	5.501	1.5	Mud	Channel
TS-10	10.0	0.094	4.278	4.372	2.2	Mud	Channel
TS-10	25.0	0.137	4.676	4.831	2.8	Mud	Channel
TS-10	40.0	0.170	3.828	3.998	4.3	Mud	Channel
TS-2	15.0	0.251	5.259	5.510	4.6	Mud	Channel
SJ-4A	43.0	0.283	3.754	4.037	7.0	Mud	Channel
TS-2	5.0	0.284	3.711	3.995	7.1	Mud	Channel
TS-5	9.0	0.485	5.466	5.951	8.1	Mud	Channel
TS-5	2.0	0.555	5.128	5.683	9.8	Sandy Mud	Channel
TS-5	35.0	0.773	5.345	6.118	12.6	Sandy Mud	Channel
TS-2	10.0	0.580	2.510	3.090	18.8	Sandy Mud	Channel
TS-PC-3	2.0	1.367	3.900	5.267	26.0	Sandy Mud	Channel
TS-5	0.1	0.766	1.268	2.034	37.7	Sandy Mud	Channel
TS-8	12.0	6.580	2.419	8.999	73.1	Muddy Sand	Point Bar
TS-8	17.0	8.257	2.400	10.657	77.5	Muddy Sand	Point Bar
TS-7	20.0	15.590	2.956	18.546	84.1	Muddy Sand	Point Bar
TS-8	5.0	18.246	3.056	21.302	85.7	Muddy Sand	Point Bar
TS-9	30.0	18.883	2.184	21.067	89.6	Sand	Point Bar
TS-3	2.0	11.314	1.114	12.428	91.0	Sand	Point Bar
TS-6	15.0	13.150	1.156	14.306	91.9	Sand	Point Bar
TS-7	30.0	18.415	1.505	19.920	92.4	Sand	Point Bar
TS-6	10.0	10.446	0.755	11.201	93.3	Sand	Point Bar
TS-7	40.0	14.354	0.955	15.309	93.8	Sand	Point Bar
TS-7	10.0	25.493	1.670	27.163	93.9	Sand	Point Bar
TS-6	5.0	11.533	0.426	11.959	96.4	Sand	Point Bar
TS-9	20.0	28.573	0.598	29.171	98.0	Sand	Point Bar
TS-9	10.0	26.799	0.557	27.356	98.0	Sand	Point Bar

* in ascending order by percent sand

APPENDIX IV

Loss-on-Ignition Data for Wetland Cores

Loss-On-Ignition by Environment

LOI Interval	Riverine	Estuarine	Palustrine	Flat	Emergent (Est.)	Emergent (Pal.)	Forested
0.0 to 5.0	41.9	0.0	0.0	0.0	0.0	0.0	0.0
5.0 to 10.0	25.8	0.0	0.0	0.0	0.0	0.0	0.0
10.0 to 15.0	12.9	37.5	0.0	11.0	45.0	13.3	0.0
15.0 to 20.0	3.2	35.0	0.0	67.0	26.0	0.0	0.0
20.0 to 25.0	6.4	10.0	0.0	22.0	6.5	0.0	7.7
25.0 to 30.0	6.4	10.0	15.4		13.0	13.3	7.7
30.0 to 35.0	3.2	5.0	23.1		6.5	26.7	15.4
35.0 to 40.0		2.5	15.4		3.2	20.0	7.7
40.0 to 45.0			11.5			6.7	15.4
45.0 to 50.0			7.7			6.7	7.7
50.0 to 55.0			7.7			6.7	7.7
55.0 to 60.0			0.0			0.0	0.0
60.0 to 65.0			3.8			0.0	7.7
65.0 to 70.0			7.7			6.7	7.7
70.0 to 75.0			7.7				15.4

Key: LOI Interval = Percent Loss-On-Ignition range
(Est.) = Estuarine
(Pal.) = Palustrine

Percent Loss-On-Ignition of Subsurface Deposits

Leipsic River Subsurface Data

Peat (High)	Mud (High)	Peat (Low)	Mud (Low)	Sandy Mud
56.0	16.0	44.3	26.3	5.2
64.8	14.7	38.0	34.0	12.4
48.7	30.9	50.2	30.1	5.0
40.9	30.3	49.6		
58.8	27.6	47.1		
66.7	28.1	44.6		
67.1	29.7	56.2		
74.1				
62.6				
46.4				
60.8				
42.8				
45.8				
64.1				
53.4				

APPENDIX IV: continued

Percent Loss-On-Ignition of Subsurface Deposits

Duck Creek Subsurface Data

Peat	Low-Organic Mud	Mud	Muddy Sand	Sandy Mud	Root Zone
50.0	8.6	16.2	25.1	38.6	40.4
79.9	9.6	18.2	5.4	12.9	28.9
38.8	10.5	19.6		14.1	48.1
61.4	7.3			11.1	27.6
39.6	8.6				
74.8	8.1				
46.2	8.6				
53.1	8.9				
	9.5				
	8.9				
	9.8				
	8.8				
	11.8				
	11.9				
	11.3				
	9.9				
	12.7				

St. Jones River Subsurface Data

Mud 1	Mud 2	Peat	Sandy Mud	Low-Organic Mud	SJ-6 Deep Mud
34.2	20.1	50.2	4.5	11.4	26.8
26.3	14.9	34.8	5.8	12.2	43.7
23.8	17.2	54.4	9.9	12.1	30.5
33.5	19.0	65.1	5.8	10.8	
24.5	16.0	43.7	14.9	10.7	
	15.7	53.4	11.3	14.6	
	19.3	47.6	3.2	12.7	
	14.4	37.9	5.9	10.4	
	14.5		7.3	10.5	
			12.5	12.9	
				15.4	
				13.3	
				15.9	
				14.1	
				10.3	
				12.1	
				10.6	
				13.7	

APPENDIX IV: continued

Loss-On-Ignition Values for Modern Wetland Environments

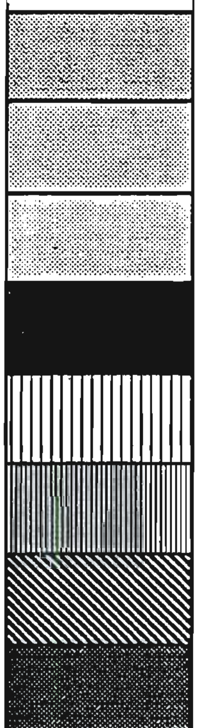
RIVERINE				ESTUARINE			PALUSTRINE								
Unconsolidated Bottom				Flat	Emr.	Total	Tot.	Tot.	Emr.	For.	Total	Emr.	For.	Emr.	For.
Mud	Sandy Mud	Sand	Total	Mud	Mud	Total	Mud	Peat	Tot.	Tot.	Total	Peat	Peat	Mud	Mud
14.7	20.5	3.1	C1+	20.3	13.8	C5+	10.7	68.3	68.3	30.6	C10+	68.3	44.9	10.7	30.6
26.2	32.6	0.5	C2+	19.1	12.8	C6	14.6	47.3	47.3	24.5	C11	47.3	54.3	14.6	24.5
15.1	7.0	1.1	C3	12.8	12.4		33.5	41.1	41.1	37.7		41.1	70.6	33.5	37.7
12.5	7.3	3.3		14.1	14.1		32.2	52.0	52.0	28.9		52.0	44.6	32.2	28.9
14.1	7.6	1.8		19.1	12.9		28.1	39.2	39.2	31.4		39.2	65.5	28.1	31.4
12.3	8.2	4.7		16.2	14.9		26.0	34.7	34.7	44.9		34.7	72.4	26.0	
	8.7	2.9		16.0	18.4		30.6	32.5	10.7	54.3		32.5	64.3		
	28.7	3.6		17.1	13.1		24.5	38.7	14.6	70.6		38.7	49.1		
	23.1	1.7		22.5	11.6		37.7	35.5	33.5	44.6		35.5			
		0.7			11.4		28.9	44.9	32.2	65.5					
		7.0			10.9		31.4	54.3	28.1	72.4					
		6.1			11.5			70.6	26.0	64.3					
		7.6			10.9			44.6	32.5	49.1					
		0.4			13.0			65.5	38.7						
		0.5			38.3			72.4	35.5						
		1.2			31.3			64.3							
					19.9			49.1							
					31.7										
					29.2										
					16.2										
					23.5										
					28.2										
					17.5										
					29.5										
					26.3										
					19.6										
					16.5										
					17.9										
					13.3										
					16.8										
					22.9										

Key: Emr. = Emergent
For. = Forested
Tot. = Total

APPENDIX V

Wetland Core Logs

LITHOLOGIES



SAND; fine (0.06 to 0.25 mm) *

SAND; medium (0.25 to 0.50 mm) *

SAND; coarse (0.50 to 1.0 mm) *

ORGANIC FRAGMENTS>2 cm diameter.

PEAT; > 18% organic carbon (Loss-On-Ignition values >35%).**

MUD; with abundant fibers, roots, stems, twigs, leaves. L.O.I. values 10-35%. ***

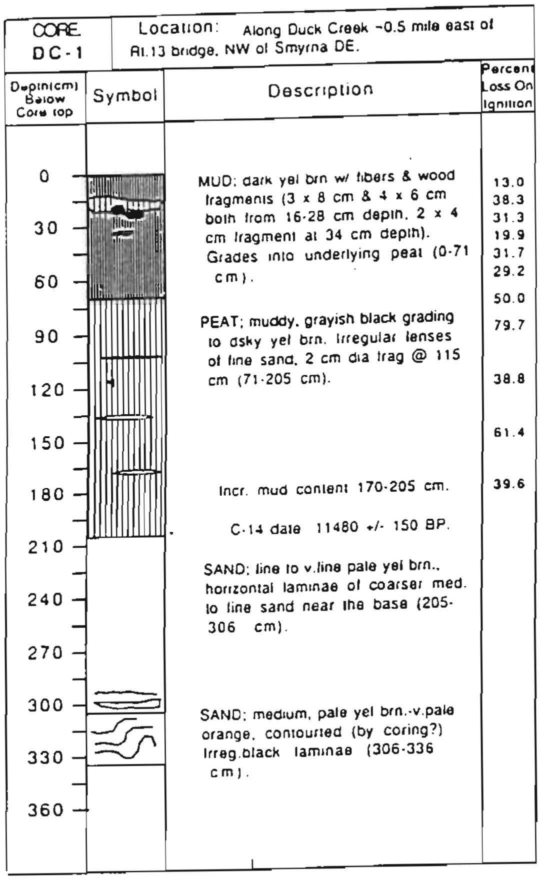
MUD; compact, lesser organic content; L.O.I. values typically<10%. ***

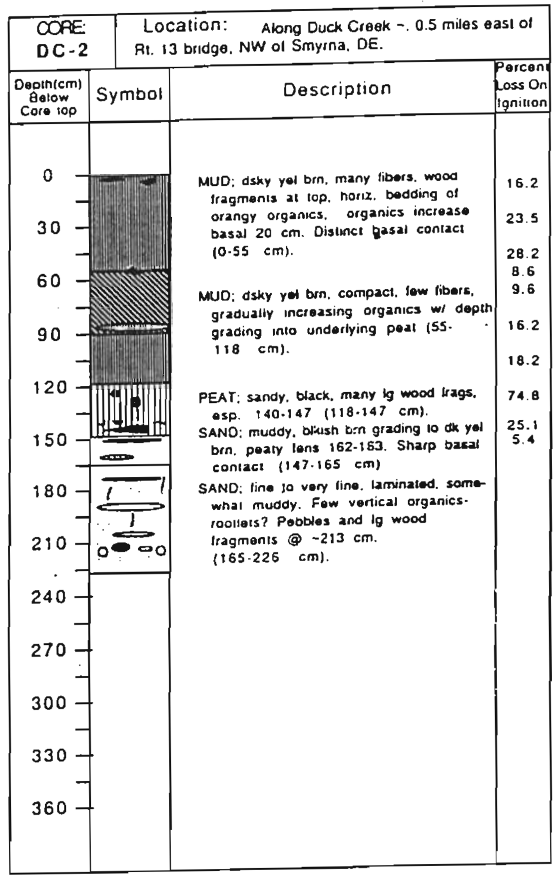
MUD; sandy. (10-50% sand) ***

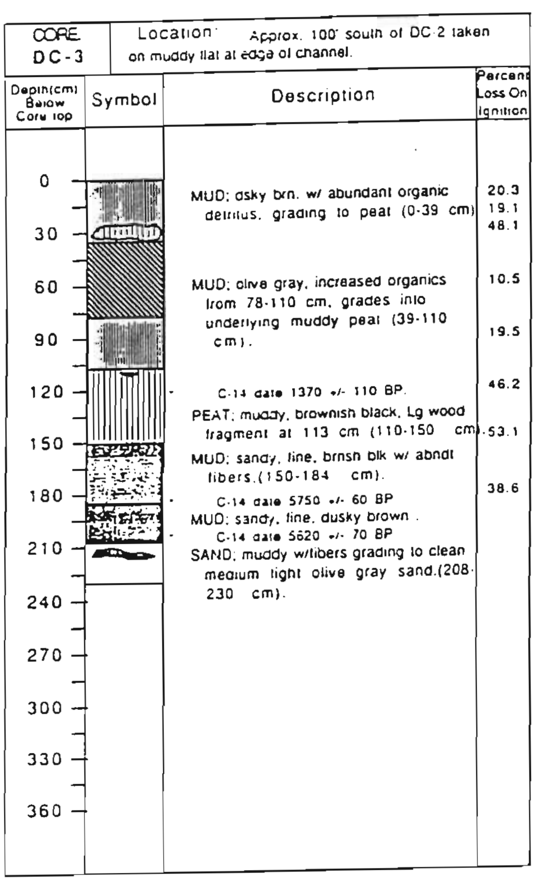
* After Compton, 1962.

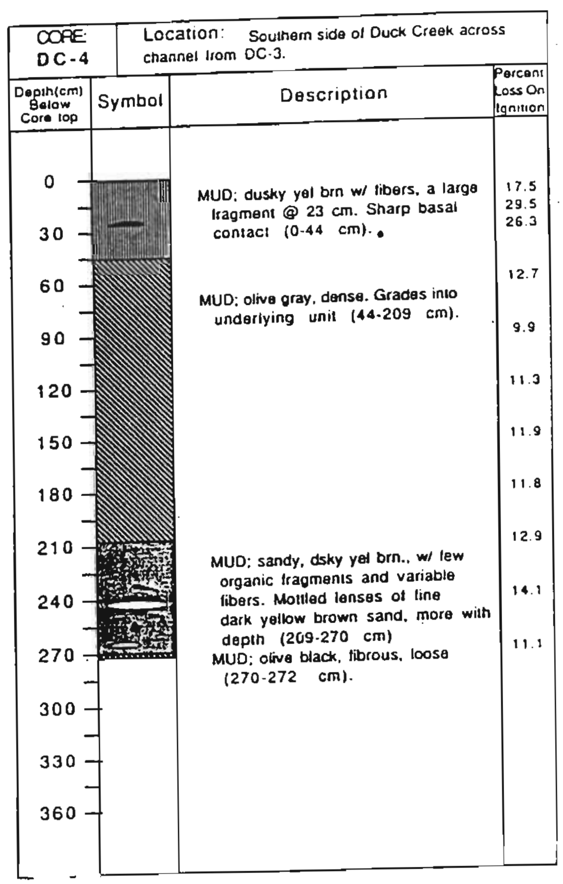
** After U.S. Soil Conservation Service, 1975.

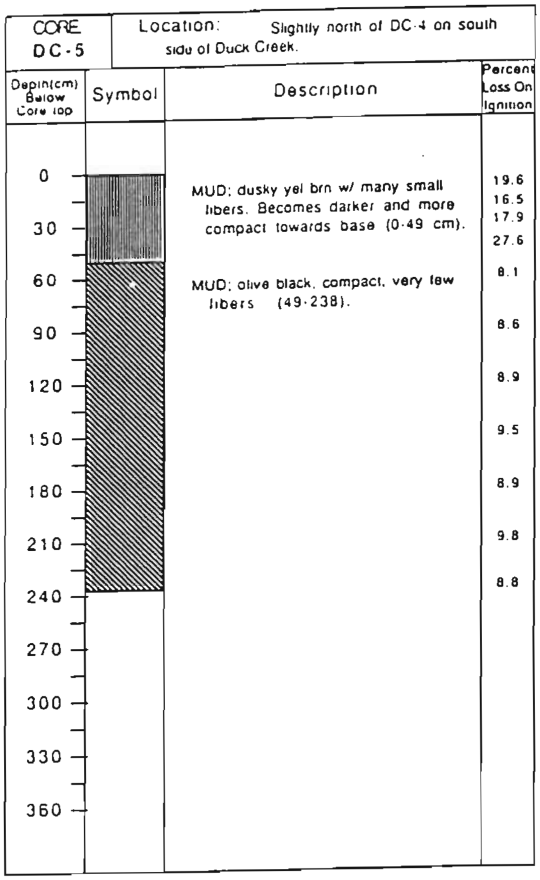
*** After Folk, Andrews, and Lewis, 1970.

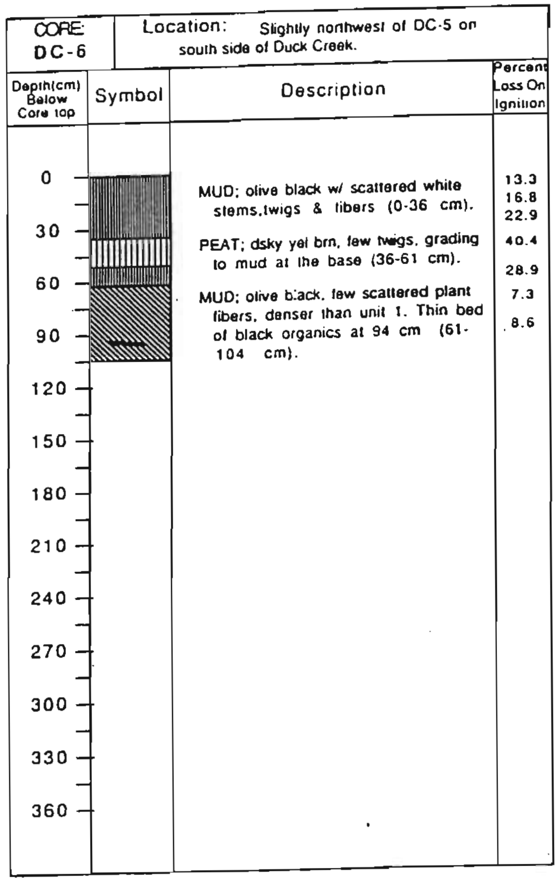

CORE DC-1
Location: Along Duck Creek ~0.5 mile east of Rt.13 bridge, NW of Smyrna DE.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
30
60
90
120
150
180
210
240
270
300
330
360
MUD; dark yel brn w/ fibers & wood fragments (3 x 8 cm & 4 x 6 cm both from 16-28 cm depth. 2 x 4 cm fragment at 34 cm depth). Grades into underlying peat (0-71 cm).
PEAT; muddy, grayish black grading to dsky yel brn. Irregular lenses of fine sand, 2 cm dia frag @ 115 cm (71-205 cm).
Incr. mud content 170-205 cm.
C-14 date 11480 +/- 150 BP.
SAND; fine to v.fine pale yel brn., horizontal laminae of coarser med. to fine sand near the base (205-306 cm).
SAND; medium, pale yel brn.-v.pale orange, contourted (by coring?) Irreg.black laminae (306-336 cm).
13.0
38.3
31.3
19.9
31.7
29.2
50.0
79.7
38.8
61.4
39.6

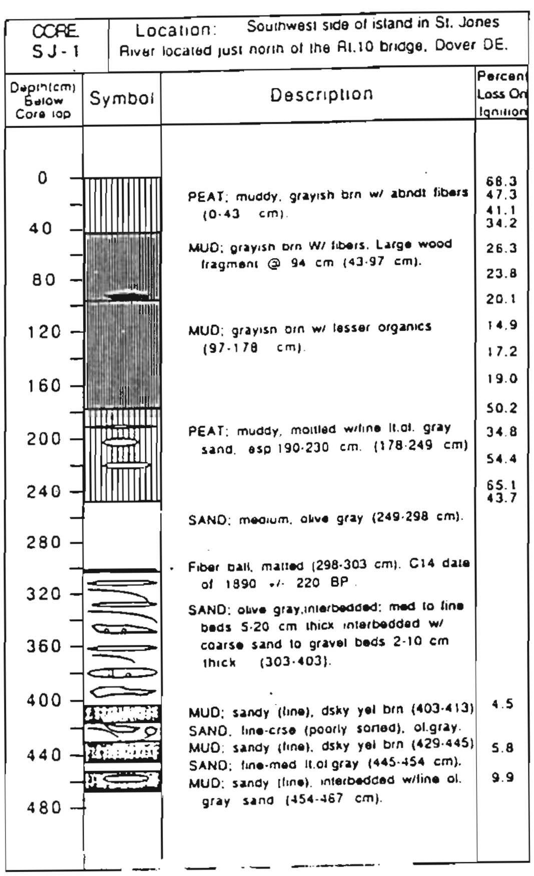

CORE DC-2
Location: Along Duck Creek ~. 0.5 miles east of Rt. 13 bridge, NW of Smyrna, DE.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
30
60
90
120
150
180
210
240
270
300
330
360
MUD; dsky yel brn, many fibers, wood fragments at top, horiz. bedding of orangy organics, organics increase basal 20 cm. Distinct basal contact (0-55 cm).
MUD; dsky yel brn, compact, few fibers, gradually increasing organics w/ depth grading into underlying peat (55-118 cm).
PEAT; sandy, black, many lg wood frags, esp. 140-147 (118-147 cm).
SAND; muddy, blkish brn grading to dk yel brn, peaty lens 162-163. Sharp basal contact (147-165 cm)
SAND; fine to very fine, laminated, somewhat muddy. Few vertical organics-rootlets? Pebbles and lg wood fragments @ ~213 cm. (165-226 cm).
16.2
23.5
28.2
8.6
9.6
16.2
18.2
74.8
25.1
5.4

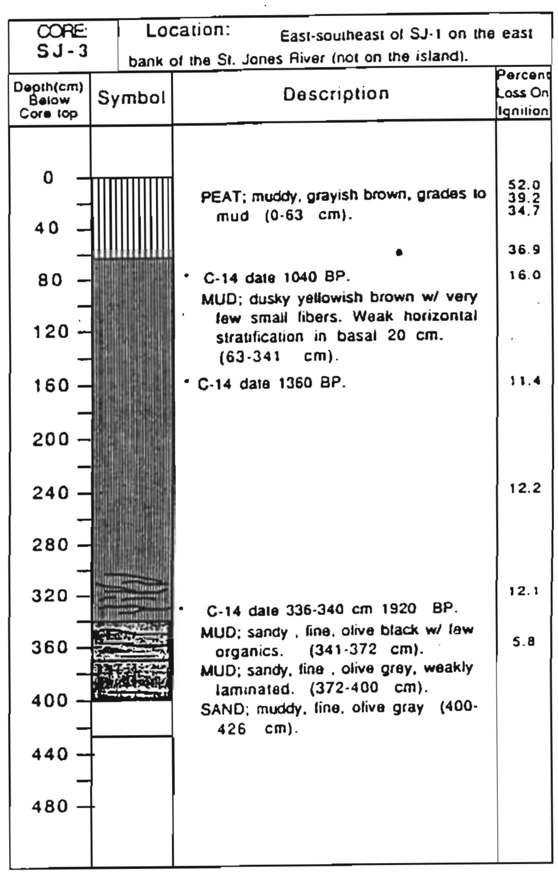

CORE DC-3
Location: Approx. 100' south of DC-2 taken on muddy flat at edge of channel.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
30
60
90
120
150
180
210
240
270
300
330
360
MUD; dsky brn. w/ abundant organic detritus, grading to peat (0-39 cm)
MUD; olive gray, increased organics from 78-110 cm, grades into underlying muddy peat (39-110 cm).
C-14 date 1370 +/- 110 BP.
PEAT; muddy, brownish black, Lg wood fragment at 113 cm (110-150 cm)
MUD; sandy, fine, brnsh blk w/ abndt fibers.(150-184 cm).
C-14 date 5750 +/- 60 BP
MUD; sandy, fine, dusky brown.
C-14 date 5620 +/- 70 BP
SAND; muddy w/fibers grading to clean medium light olive gray sand.(208-230 cm).
20.3
19.1
48.1
10.5
19.5
46.2
53.1
38.6

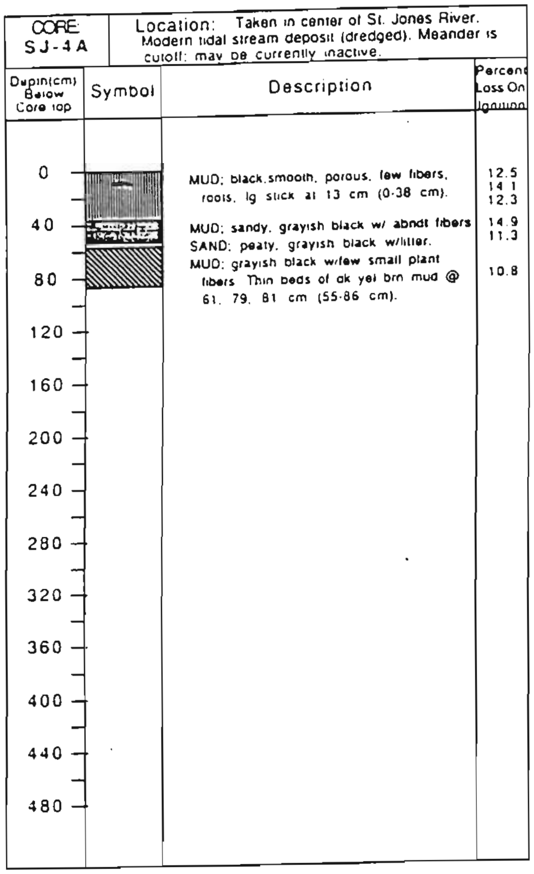

CORE DC-4
Location: Southern side of Duck Creek across channel from DC-3.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
30
60
90
120
150
180
210
240
270
300
330
360
MUD; dusky yel brn w/ fibers, a large fragment @ 23 cm. Sharp basal contact (0-44 cm).
MUD; olive gray, dense. Grades into underlying unit (44-209 cm).
MUD; sandy, dsky yel brn., w/ few organic fragments and variable fibers. Mottled lenses of fine dark yellow brown sand, more with depth (209-270 cm)
MUD; olive black, fibrous, loose (270-272 cm).
17.5
29.5
26.3
12.7
9.9
11.3
11.9
11.8
12.9
14.1
11.1

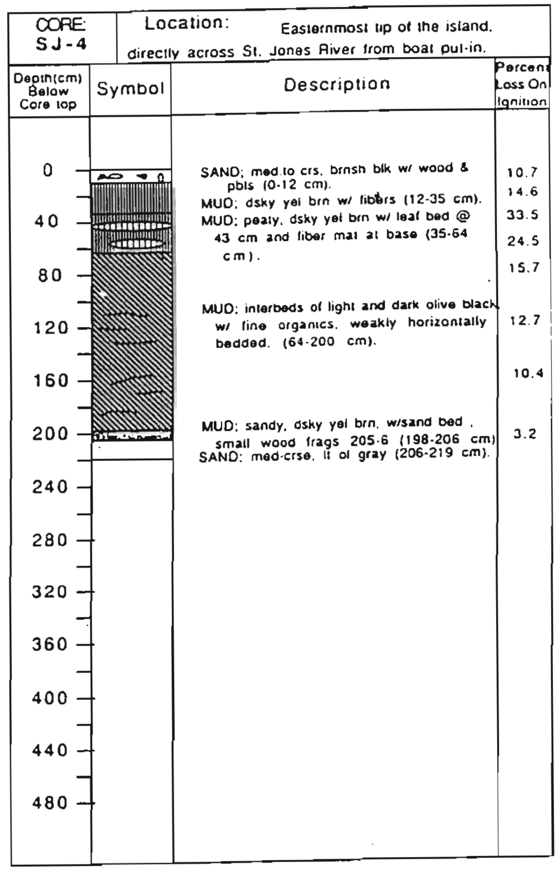

CORE DC-5
Location: Slightly north of DC-4 on south side of Duck Creek.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
30
60
90
120
150
180
210
240
270
300
330
360
MUD; dusky yel brn w/ many small fibers. Becomes darker and more compact towards base (0-49 cm).
MUD; olive black, compact, very few fibers (49-238).
19.6
16.5
17.9
27.6
8.1
8.6
8.9
9.5
8.9
9.8
8.8

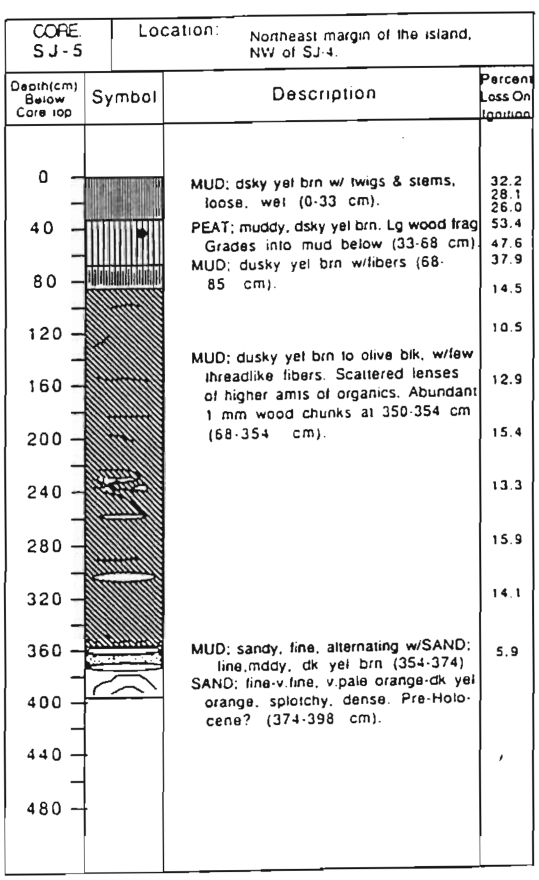

CORE DC-6
Location: Slightly northwest of DC-5 on south side of Duck Creek.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
30
60
90
120
150
180
210
240
270
300
330
360
MUD; olive black w/ scattered white stems,twigs & fibers (0-36 cm).
PEAT; dsky yel brn, few twigs, grading to mud at the base (36-61 cm).
MUD; olive black, few scattered plant fibers, denser than unit 1. Thin bed of black organics at 94 cm (61-104 cm).
13.3
16.8
22.9
40.4
28.9
7.3
8.6

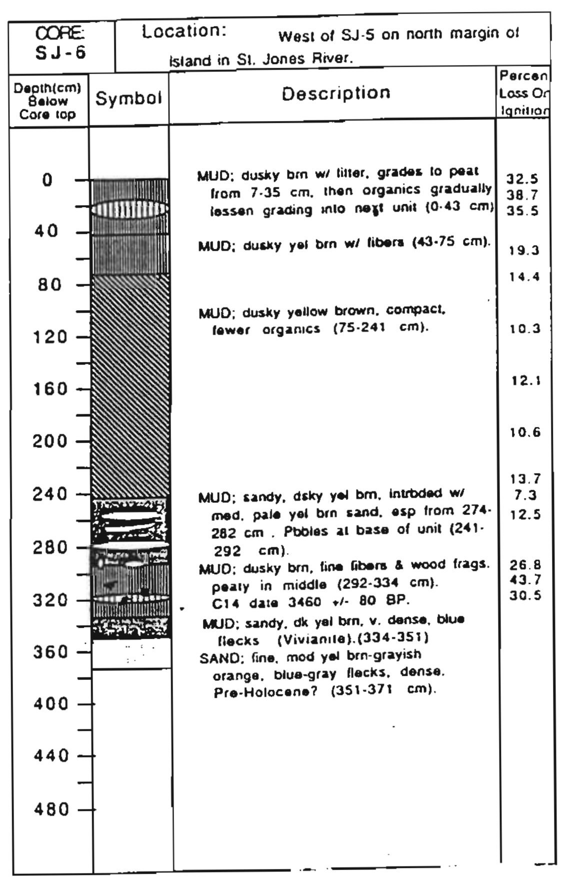

CORE SJ-1
Location: Southwest side of island in St. Jones River located just north of the Rt.10 bridge, Dover DE.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
40
80
120
160
200
240
280
320
360
400
440
480
PEAT; muddy, grayish brn w/ abndt fibers (0-43 cm).
MUD; grayish brn W/ fibers. Large wood fragment @ 94 cm (43-97 cm).
MUD; grayish brn w/ lesser organics (97-178 cm).
PEAT; muddy, mottled w/fine lt.ol. gray sand, esp 190-230 cm. (178-249 cm)
SAND; medium, olive gray (249-298 cm).
Fiber ball, matted (298-303 cm). C14 date of 1890 +/- 220 BP.
SAND; olive gray,interbedded; med to fine beds 5-20 cm thick interbedded w/ coarse sand to gravel beds 2-10 cm thick (303-403).
MUD; sandy (fine), dsky yel brn (403-413)
SAND, fine-crse (poorly sorted), ol.gray.
MUD; sandy (fine), dsky yel brn (429-445)
SAND; fine-med lt.ol gray (445-454 cm).
MUD; sandy (fine), interbedded w/fine ol. gray sand (454-467 cm).
68.3
47.3
41.1
34.2
26.3
23.8
20.1
14.9
17.2
19.0
50.2
34.8
54.4
65.1
43.7
4.5
5.8
9.9

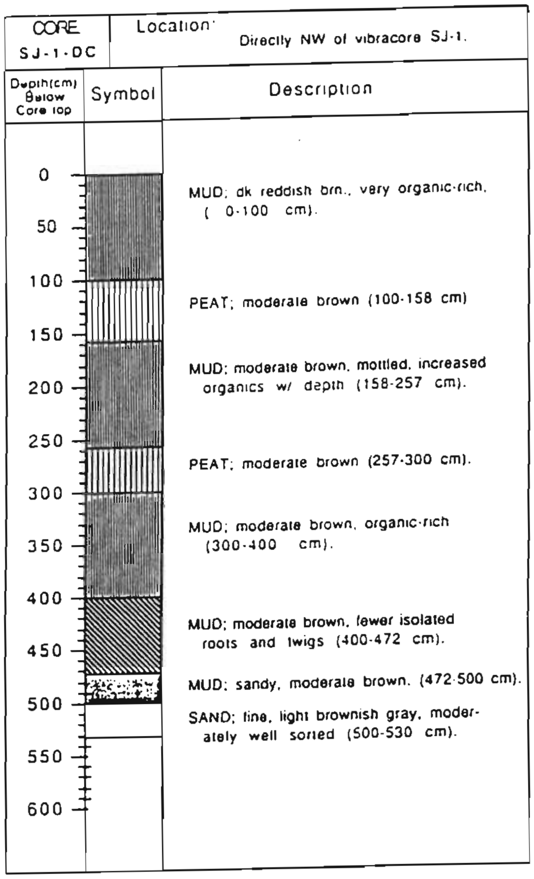

CORE SJ-3
Location: East-southeast of SJ-1 on the east bank of the St. Jones River (not on the island).
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
40
80
120
160
200
240
280
320
360
400
440
480
PEAT; muddy, grayish brown, grades to mud (0-63 cm).
C-14 date 1040 BP.
MUD; dusky yellowish brown w/ very few small fibers. Weak horizontal stratification in basal 20 cm. (63-341 cm).
C-14 date 1360 BP.
C-14 date 336-340 cm 1920 BP.
MUD; sandy , fine, olive black w/ few organics. (341-372 cm).
MUD; sandy, fine , olive grey, weakly laminated. (372-400 cm).
SAND; muddy, fine, olive gray (400-426 cm).
52.0
39.2
34.7
36.9
16.0
11.4
12.2
12.1
5.8

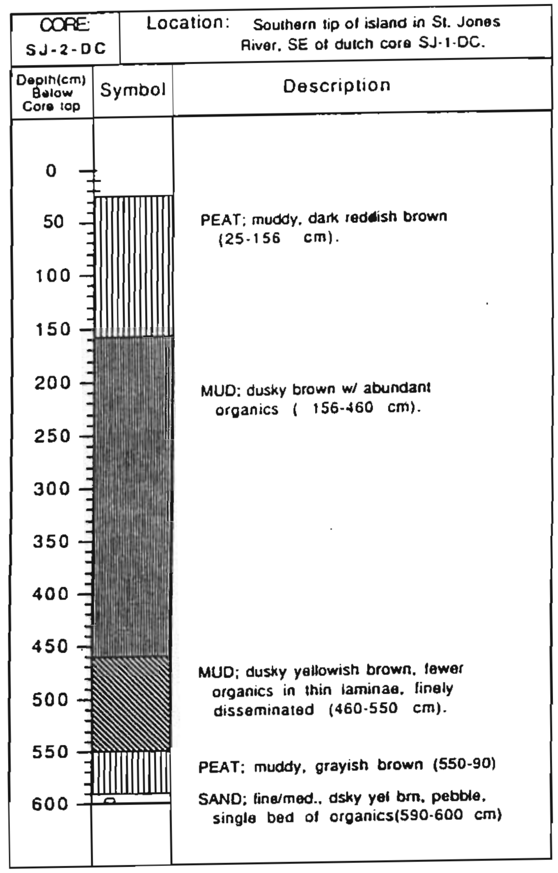

CORE: SJ-4A
Location: Taken in center of St. Jones River. Modern tidal stream deposit (dredged). Meander is cutoff: may be currently inactive.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0 40 80 120 160 200 240 280 320 360 400 440 480
MUD; black,smooth, porous, few fibers, roots, lg stick at 13 cm (0-38 cm).
MUD; sandy, grayish black w/ abndt fibers
SAND; peaty, grayish black w/litter.
MUD; grayish black w/few small plant fibers. Thin beds of dk yel brn mud @ 61, 79, 81 cm (55-86 cm).
12.5
14.1
12.3
14.9
11.3
10.8

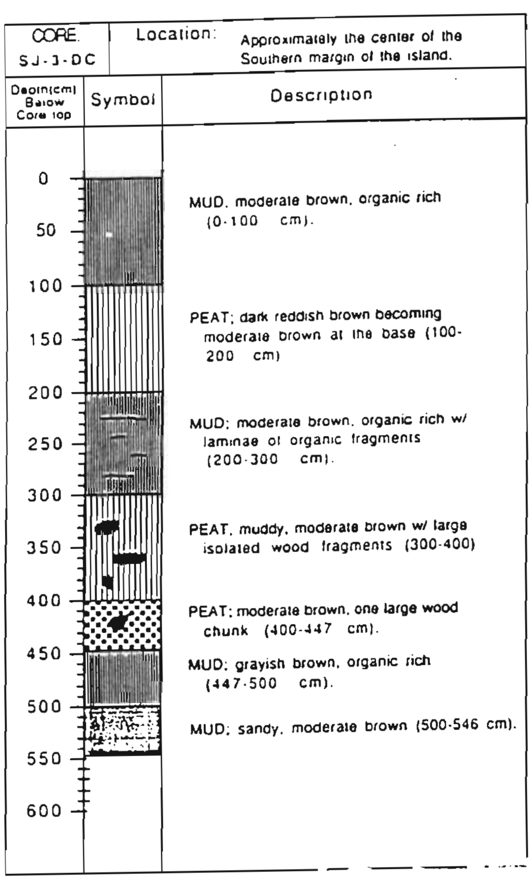

CORE: SJ-4
Location: Easternmost tip of the island, directly across St. Jones River from boat put-in.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0 40 80 120 160 200 240 280 320 360 400 440 480
SAND; med.to crs, brnsh blk w/ wood & pbls (0-12 cm).
MUD; dsky yel brn w/ fibers (12-35 cm).
MUD; peaty, dsky yel brn w/ leaf bed @ 43 cm and fiber mat at base (35-64 cm).
MUD; interbeds of light and dark olive black w/ fine organics, weakly horizontally bedded. (64-200 cm).
MUD; sandy, dsky yel brn, w/sand bed, small wood frags 205-6 (198-206 cm)
SAND; med-crse, lt ol gray (206-219 cm).
10.7
14.6
33.5
24.5
15.7
12.7
10.4
3.2

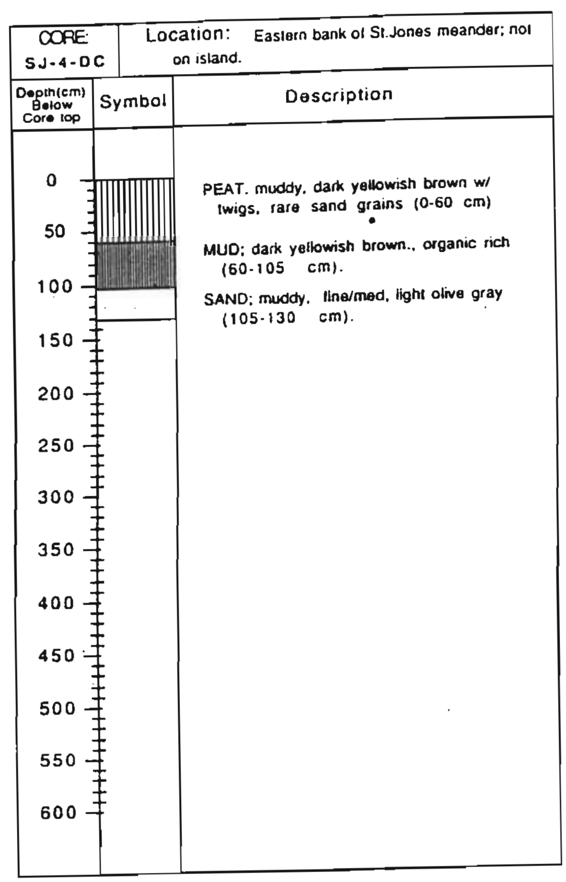

CORE: SJ-5
Location: Northeast margin of the island, NW of SJ-4.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0 40 80 120 160 200 240 280 320 360 400 440 480
MUD; dsky yel brn w/ twigs & stems, loose, wet (0-33 cm).
PEAT; muddy, dsky yel brn. Lg wood frag Grades into mud below (33-68 cm).
MUD; dusky yel brn w/fibers (68-85 cm).
MUD; dusky yel brn to olive blk, w/few threadlike fibers. Scattered lenses of higher amts of organics. Abundant 1 mm wood chunks at 350-354 cm (68-354 cm).
MUD; sandy, fine, alternating w/SAND; fine,mddy, dk yel brn (354-374)
SAND; fine-v.fine, v.pale orange-dk yel orange, splotchy, dense. Pre-Holocene? (374-398 cm).
32.2
28.1
26.0
53.4
47.6
37.9
14.5
10.5
12.9
15.4
13.3
15.9
14.1
5.9

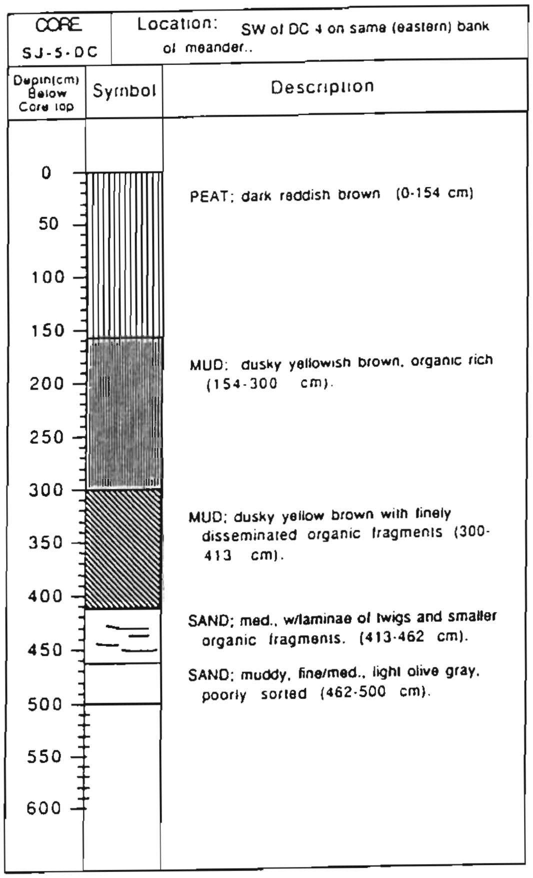

CORE: SJ-6
Location: West of SJ-5 on north margin of island in St. Jones River.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0 40 80 120 160 200 240 280 320 360 400 440 480
MUD; dusky brn w/ litter, grades to peat from 7-35 cm, then organics gradually lessen grading into next unit (0-43 cm)
MUD; dusky yel brn w/ fibers (43-75 cm).
MUD; dusky yellow brown, compact, fewer organics (75-241 cm).
MUD; sandy, dsky yel brn, intrbded w/ med, pale yel brn sand, esp from 274-282 cm. Pbbles at base of unit (241-292 cm).
MUD; dusky brn, fine fibers & wood frags, peaty in middle (292-334 cm). C14 date 3460 +/- 80 BP.
MUD; sandy, dk yel brn, v. dense, blue flecks (Vivianite).(334-351)
SAND; fine, mod yel brn-grayish orange, blue-gray flecks, dense. Pre-Holocene? (351-371 cm).
32.5
38.7
35.5
19.3
14.4
10.3
12.1
10.6
13.7
7.3
12.5
26.8
43.7
30.5

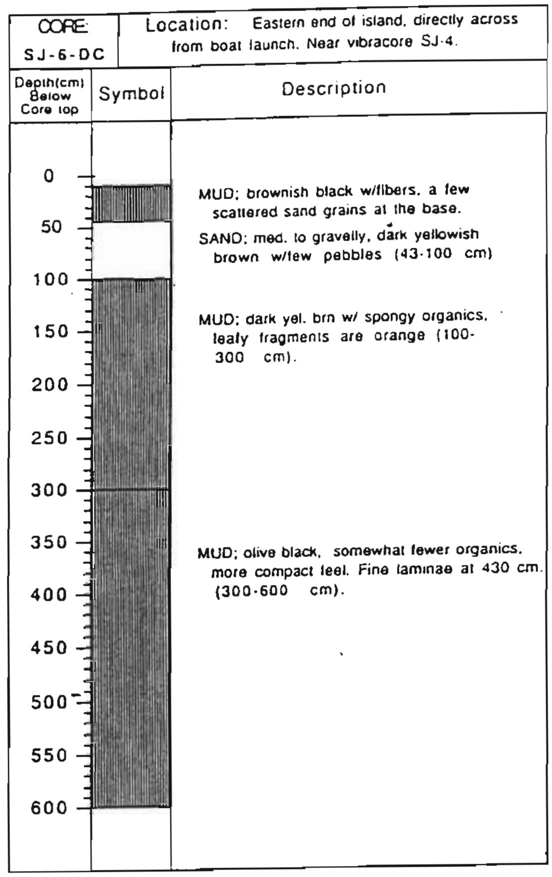

CORE
SJ-1-DC
Location: Directly NW of vibracore SJ-1.
Depth(cm) Below Core top
Symbol
Description
0 50 100 150 200 250 300 350 400 450 500 550 600
MUD; dk reddish brn., very organic-rich, (0-100 cm).
PEAT; moderate brown (100-158 cm)
MUD; moderate brown, mottled, increased organics w/ depth (158-257 cm).
PEAT; moderate brown (257-300 cm).
MUD; moderate brown, organic-rich (300-400 cm).
MUD; moderate brown, fewer isolated roots and twigs (400-472 cm).
MUD; sandy, moderate brown. (472-500 cm).
SAND; fine, light brownish gray, moderately well sorted (500-530 cm).

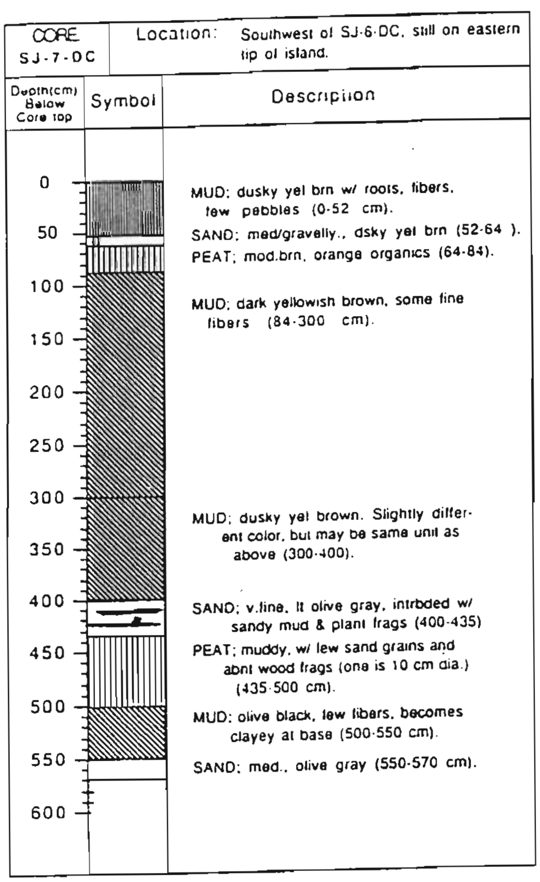

CORE
SJ-2-DC
Location: Southern tip of island in St. Jones River, SE of dutch core SJ-1-DC.
Depth(cm) Below Core top
Symbol
Description
0 50 100 150 200 250 300 350 400 450 500 550 600
PEAT; muddy, dark reddish brown (25-156 cm).
MUD; dusky brown w/ abundant organics (156-460 cm).
MUD; dusky yellowish brown, fewer organics in thin laminae, finely disseminated (460-550 cm).
PEAT; muddy, grayish brown (550-90)
SAND; fine/med., dsky yel brn, pebble, single bed of organics(590-600 cm)

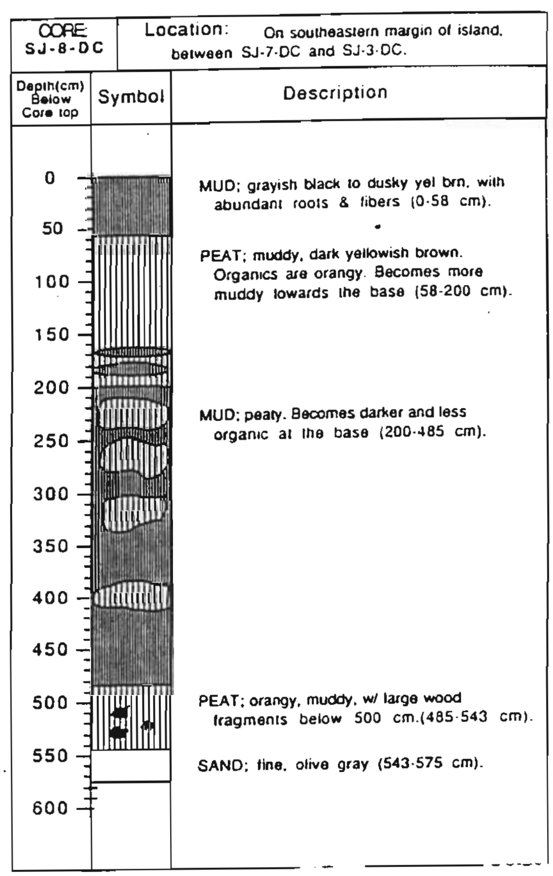

CORE
SJ-3-DC
Location: Approximately the center of the Southern margin of the island.
Depth(cm) Below Core top
Symbol
Description
0 50 100 150 200 250 300 350 400 450 500 550 600
MUD, moderate brown, organic rich (0-100 cm).
PEAT; dark reddish brown becoming moderate brown at the base (100-200 cm)
MUD; moderate brown, organic rich w/ laminae of organic fragments (200-300 cm).
PEAT, muddy, moderate brown w/ large isolated wood fragments (300-400)
PEAT; moderate brown, one large wood chunk (400-447 cm).
MUD; grayish brown, organic rich (447-500 cm).
MUD; sandy, moderate brown (500-546 cm).

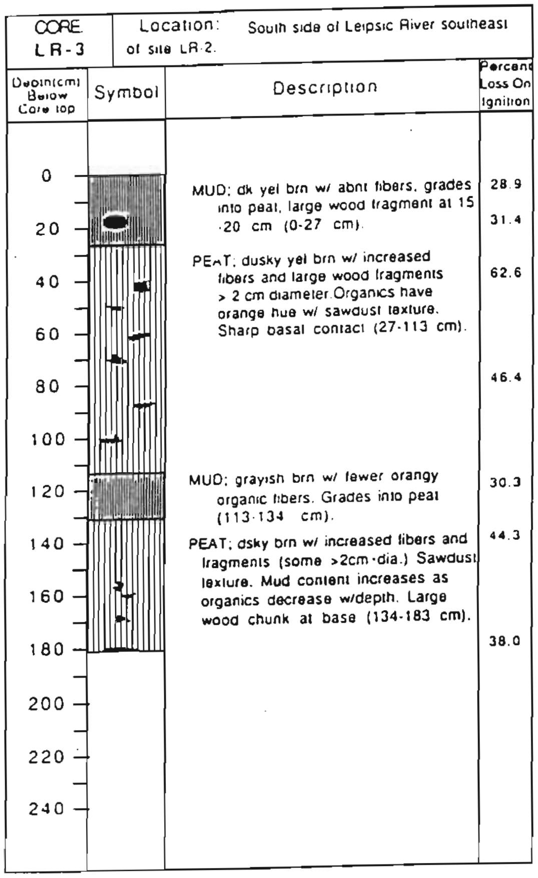

CORE
SJ-4-DC
Location: Eastern bank of St.Jones meander; not on island.
Depth(cm) Below Core top
Symbol
Description
0 50 100 150 200 250 300 350 400 450 500 550 600
PEAT, muddy, dark yellowish brown w/ twigs, rare sand grains (0-60 cm)
MUD; dark yellowish brown., organic rich (60-105 cm).
SAND; muddy, fine/med, light olive gray (105-130 cm).

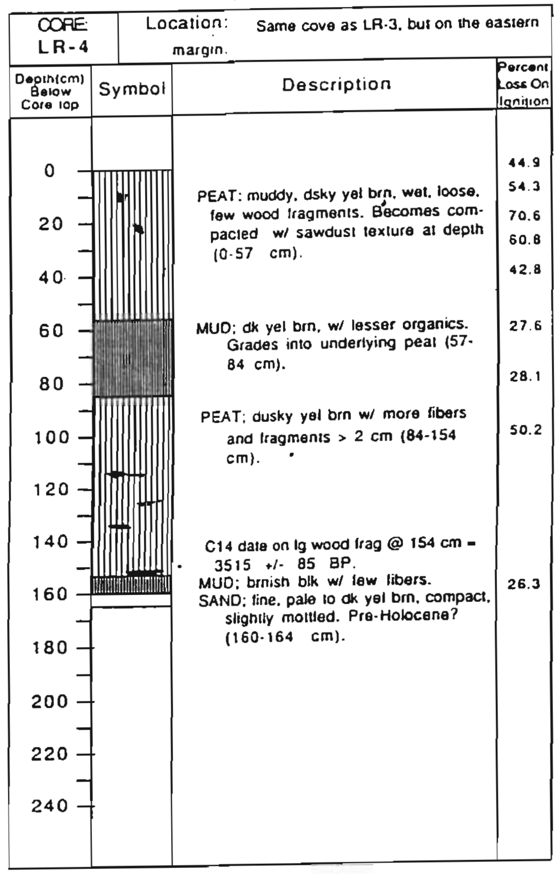

CORE SJ-5-DC
Location: SW of DC 4 on same (eastern) bank of meander..
Depth(cm) Below Core top
Symbol
Description
0 50 100 150 200 250 300 350 400 450 500 550 600
PEAT: dark reddish brown (0-154 cm)
MUD: dusky yellowish brown, organic rich (154-300 cm).
MUD: dusky yellow brown with finely disseminated organic fragments (300-413 cm).
SAND: med., w/laminae of twigs and smaller organic fragments. (413-462 cm).
SAND: muddy, fine/med., light olive gray, poorly sorted (462-500 cm).

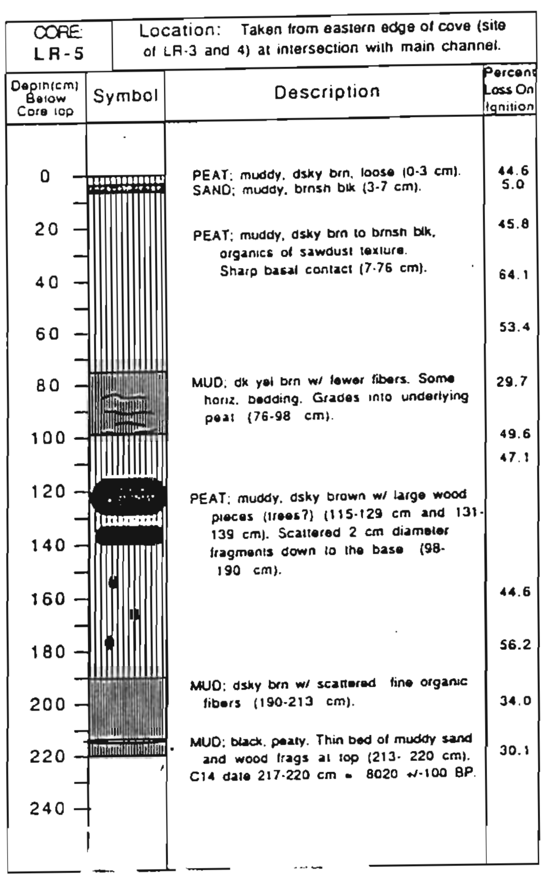

CORE SJ-6-DC
Location: Eastern end of island, directly across from boat launch. Near vibracore SJ-4.
Depth(cm) Below Core top
Symbol
Description
0 50 100 150 200 250 300 350 400 450 500 550 600
MUD: brownish black w/fibers, a few scattered sand grains at the base.
SAND: med. to gravelly, dark yellowish brown w/few pebbles (43-100 cm)
MUD: dark yel. brn w/ spongy organics, leafy fragments are orange (100-300 cm).
MUD: olive black, somewhat fewer organics, more compact feel. Fine laminae at 430 cm. (300-600 cm).


CORE SJ-7-DC
Location: Southwest of SJ-6-DC, still on eastern tip of island.
Depth(cm) Below Core top
Symbol
Description
0 50 100 150 200 250 300 350 400 450 500 550 600
MUD: dusky yel brn w/ roots, fibers, few pebbles (0-52 cm).
SAND: med/gravelly., dsky yel brn (52-64).
PEAT: mod.brn, orange organics (64-84).
MUD: dark yellowish brown, some fine fibers (84-300 cm).
MUD: dusky yel brown. Slightly different color, but may be same unit as above (300-400).
SAND: v.fine, lt olive gray, intrbded w/ sandy mud & plant frags (400-435)
PEAT: muddy, w/ few sand grains and abnt wood frags (one is 10 cm dia.) (435-500 cm).
MUD: olive black, few fibers, becomes clayey at base (500-550 cm).
SAND: med., olive gray (550-570 cm).


CORE SJ-8-DC
Location: On southeastern margin of island, between SJ-7-DC and SJ-3-DC.
Depth(cm) Below Core top
Symbol
Description
0 50 100 150 200 250 300 350 400 450 500 550 600
MUD; grayish black to dusky yel brn, with abundant roots & fibers (0-58 cm).
PEAT; muddy, dark yellowish brown. Organics are orangy. Becomes more muddy towards the base (58-200 cm).
MUD; peaty. Becomes darker and less organic at the base (200-485 cm).
PEAT; orangy, muddy, w/ large wood fragments below 500 cm.(485-543 cm).
SAND; fine, olive gray (543-575 cm).


CORE LR-3
Location: South side of Leipsic River southeast of site LR-2.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
20
40
60
80
100
120
140
160
180
200
220
240
MUD: dk yel brn w/ abnt fibers, grades into peat, large wood fragment at 15-20 cm (0-27 cm).
PEAT: dusky yel brn w/ increased fibers and large wood fragments > 2 cm diameter. Organics have orange hue w/ sawdust texture. Sharp basal contact (27-113 cm).
MUD: grayish brn w/ fewer orangy organic fibers. Grades into peat (113-134 cm).
PEAT: dsky brn w/ increased fibers and fragments (some >2cm-dia.) Sawdust texture. Mud content increases as organics decrease w/depth. Large wood chunk at base (134-183 cm).
28.9
31.4
62.6
46.4
30.3
44.3
38.0


CORE LR-4
Location: Same cove as LR-3, but on the eastern margin.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
20
40
60
80
100
120
140
160
180
200
220
240
PEAT: muddy, dsky yel brn, wet, loose, few wood fragments. Becomes compacted w/ sawdust texture at depth (0-57 cm).
MUD: dk yel brn, w/ lesser organics. Grades into underlying peat (57-84 cm).
PEAT: dusky yel brn w/ more fibers and fragments > 2 cm (84-154 cm).
C14 date on lg wood frag @ 154 cm = 3515 +/- 85 BP.
MUD: brnish blk w/ few fibers.
SAND: fine, pale to dk yel brn, compact, slightly mottled. Pre-Holocene? (160-164 cm).
44.9
54.3
70.6
60.8
42.8
27.6
28.1
50.2
26.3


CORE LR-5
Location: Taken from eastern edge of cove (site of LR-3 and 4) at intersection with main channel.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
20
40
60
80
100
120
140
160
180
200
220
240
PEAT: muddy, dsky brn, loose (0-3 cm).
SAND: muddy, brnsh blk (3-7 cm).
PEAT: muddy, dsky brn to brnsh blk, organics of sawdust texture. Sharp basal contact (7-76 cm).
MUD: dk yel brn w/ fewer fibers. Some horiz. bedding. Grades into underlying peat (76-98 cm).
PEAT: muddy, dsky brown w/ large wood pieces (trees?) (115-129 cm and 131-139 cm). Scattered 2 cm diameter fragments down to the base (98-190 cm).
MUD: dsky brn w/ scattered fine organic fibers (190-213 cm).
MUD: black, peaty. Thin bed of muddy sand and wood frags at top (213- 220 cm). C14 date 217-220 cm = 8020 +/-100 BP.
44.6
5.0
45.8
64.1
53.4
29.7
49.6
47.1
44.6
56.2
34.0
30.1

CORE TS-1	Location: Tidal stream ~0.6 mi. south of Mill Creek fork ~1.5 mi. east of Smyrna DE	
Depth (cm) Below Core top	**Description**	**Percent Loss On Ignition**
0–20	PEAT. muddy, dusky brn w/abndt matted fibers, roots, blades of grasses, rhizomes. Grades into unit 2 (0-20 cm).	65.5, 72.4, 64.3, 49.1
20–118	MUD; olive black to dsky yel brn w/ lesser but still abndt stems & fibers. Many 1mm thick peat lenses. Sharp contact w/ unit 3 (20-118 cm).	21.0, 15.9, 13.9, 12.4, 12.4
118–124	PEAT. dense, grayish black w/fibers and wood chunks, little mud. Large (1.5 cm dia.) wood frg. at base (118-124 cm).	87.2

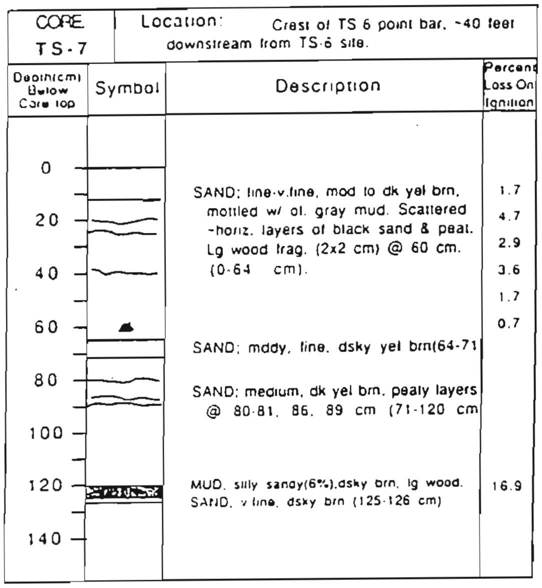
CORE TS-2	Location: Downstream (north) ~0.1 mile from TS-1 site.	
Depth (cm) Below Core top	**Description**	**Percent Loss On Ignition**
0–12	MUD; sandy (6-13%), gray blk, mealy fibers, wood chunks, lg stick (0-12 cm).	20.5, 32.6, 14.0
12–42	MUD; olive black, more compact w/less fibers except in horiz. beds 1mm thick througnout, fiber layer at base (12-42 cm).	16.9, 15.2, 27.9
42–58	MUD; olive blk, peaty at depth, lg wood fragment, twig layer 52-53 cm (42-58 cm).	30.3, 40.3, 22.4
58–75	MUD. olive black, finely organic, clayey (58-75 cm).	17.0, 13.2

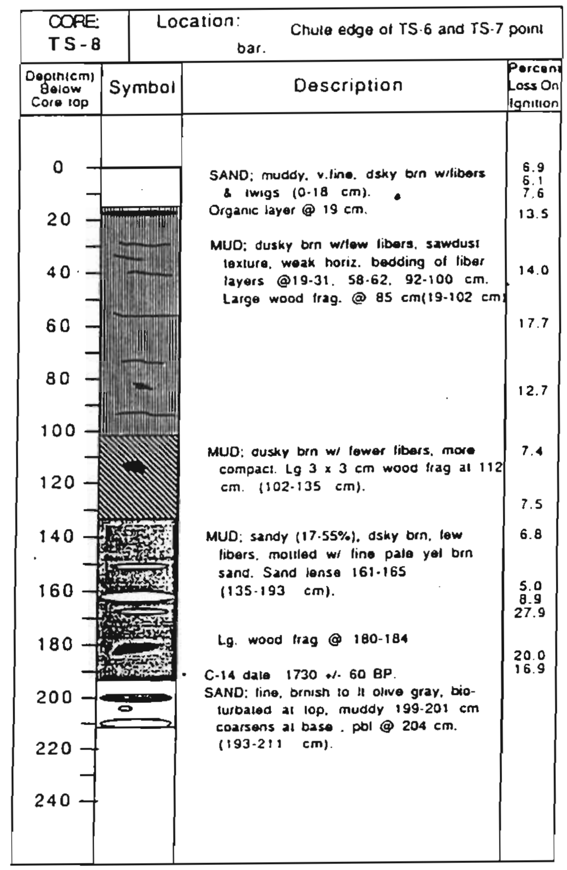
CORE TS-3	Location: Downstream (northwest) ~ 0.1 mile from TS-2 site.	
Depth (cm) Below Core top	**Description**	**Percent Loss On Ignition**
0–5	SAND; muddy, fine, dk yel brn w/plant fragments (0-5 cm).	3.1
5–79	MUD; dsky yel brn, dense, few fibers. Black beds 1-2 mm thick scattered throughout (5-79 cm).	8.1, 9.0, 9.8, 9.2
79–94	MUD; sandy, brownish black, mottled w/ 4 mm thick pods of fine to med. dk yel brn sand (79-94 cm).	7.5, 15.2

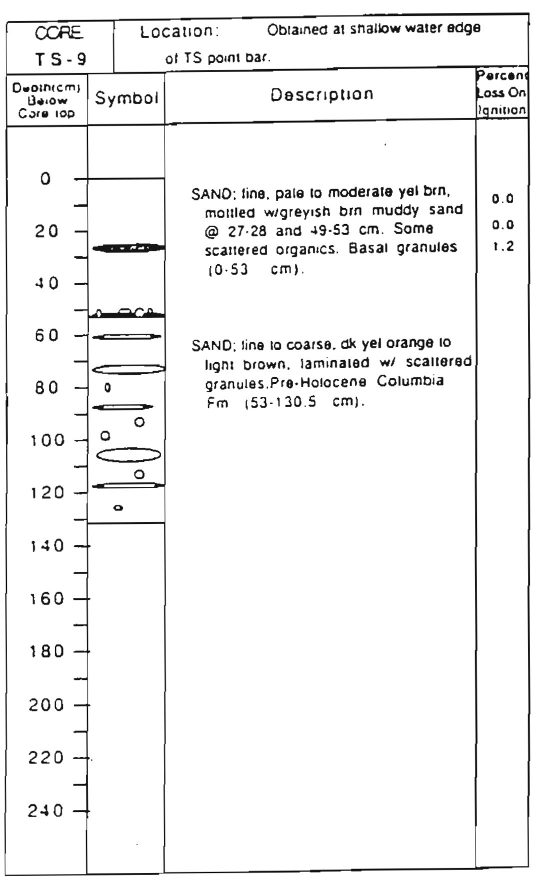
CORE TS-4	Location: North bank of confluence of two tributaries ~0.1 mi. south of Mill Creek fork.	
Depth (cm) Below Core top	**Description**	**Percent Loss On Ignition**
0–76	MUD; slightly sandy, olive black, gradational increase in sand content and compactness downsection (0-76 cm).	12.6, 14.1, 19.1, 18.2, 8.1, 11.5
76–97	MUD; olive black, very compact w/few fibers (76-97 cm).	8.5

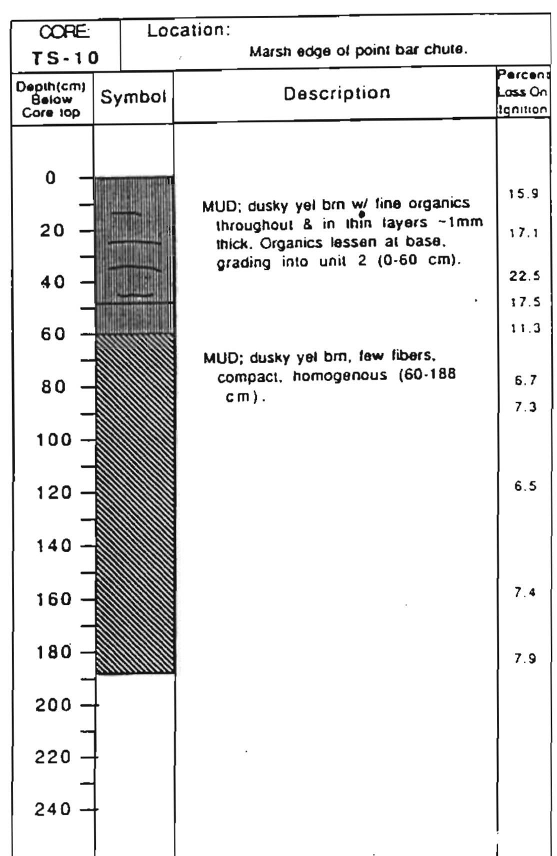
CORE TS-5	Location: Directly across stream from TS-4, on south bank.	
Depth (cm) Below Core top	**Description**	**Percent Loss On Ignition**
0–1	MUD: sandy (35%), ol.blk (0-1 cm).	7.0, 7.3
1–70	MUD: slightly sandy (8-14 %), olive black, dense"clayey", diagonal cracks @ 3-6 cm and 15 cm, surrounded by mottled yel brn mud. Very few organics (1-70 cm).	7.6, 8.2, 8.7

CORE TS-6	Location: Upstream (south) end of sandy point bar on sharp bend ~0.2 mi. downstream from Mill Creek fork.	
Depth (cm) Below Core top	**Description**	**Percent Loss On Ignition**
0–15	SAND: med.-fine, dk yel brn, fines downward. Lg wood fragments (0-15 cm)	0.5, [illegible]
15–18	SAND: fine, muddy, dsky yel brn (15-18)	3.3
18–41	MUD: dsky yel brn w/ ~horizontal beds of small organics (18-41 cm).	14.1, 13.2, 15.5
41–44	SAND: muddy, fine, dusky yel brn w/wood fragments ~1-5 mm (41-44 cm).	4.5


CORE
TS-7
Location: Crest of TS 6 point bar, ~40 feet downstream from TS-6 site.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
20
40
60
80
100
120
140
SAND; fine-v.fine, mod to dk yel brn, mottled w/ ol. gray mud. Scattered ~horiz. layers of black sand & peat. Lg wood frag. (2x2 cm) @ 60 cm. (0-64 cm).
SAND; mddy, fine, dsky yel brn(64-71
SAND; medium, dk yel brn, peaty layers @ 80-81, 86, 89 cm (71-120 cm
MUD, silty sandy(6%),dsky brn, lg wood. SAND, v fine, dsky brn (125-126 cm)
1.7
4.7
2.9
3.6
1.7
0.7
16.9


CORE:
TS-8
Location: Chute edge of TS-6 and TS-7 point bar.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
20
40
60
80
100
120
140
160
180
200
220
240
SAND; muddy, v.fine, dsky brn w/fibers & twigs (0-18 cm).
Organic layer @ 19 cm.
MUD; dusky brn w/few fibers, sawdust texture, weak horiz. bedding of fiber layers @19-31, 58-62, 92-100 cm. Large wood frag. @ 85 cm(19-102 cm)
MUD; dusky brn w/ fewer fibers, more compact. Lg 3 x 3 cm wood frag at 112 cm. (102-135 cm).
MUD; sandy (17-55%), dsky brn, few fibers, mottled w/ fine pale yel brn sand. Sand lense 161-165 (135-193 cm).
Lg. wood frag @ 180-184
C-14 date 1730 +/- 60 BP.
SAND; fine, brnish to lt olive gray, bio-turbated at top, muddy 199-201 cm coarsens at base . pbl @ 204 cm. (193-211 cm).
6.9
6.1
7.6
13.5
14.0
17.7
12.7
7.4
7.5
6.8
5.0
8.9
27.9
20.0
16.9


CORE
TS-9
Location: Obtained at shallow water edge of TS point bar.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
20
40
60
80
100
120
140
160
180
200
220
240
SAND; fine, pale to moderate yel brn, mottled w/greyish brn muddy sand @ 27-28 and 49-53 cm. Some scattered organics. Basal granules (0-53 cm).
SAND; fine to coarse, dk yel orange to light brown, laminated w/ scattered granules.Pre-Holocene Columbia Fm (53-130.5 cm).
0.0
0.0
1.2


CORE:
TS-10
Location: Marsh edge of point bar chute.
Depth(cm) Below Core top
Symbol
Description
Percent Loss On Ignition
0
20
40
60
80
100
120
140
160
180
200
220
240
MUD; dusky yel brn w/ fine organics throughout & in thin layers ~1mm thick. Organics lessen at base, grading into unit 2 (0-60 cm).
MUD; dusky yel brn, few fibers, compact, homogenous (60-188 cm).
15.9
17.1
22.5
17.5
11.3
6.7
7.3
6.5
7.4
7.9

CORE TS-PC-1	Location: Marsh surface, west bank of channel, site of TS-DC 1		
Depth(cm) Below Core top	Symbol	Description	Percent Loss On Ignition
0 20		MUD; dark yel brn w/abnt matted roots, stems, fibers,rhizomes (0-11 cm). MUD; dsky yel brn w/lesser fibers, not matted (11-29 cm).	13.8 12.8 12.4 12 2 11 5 11.0

CORE TS-PC-2	Location: Same as TS-DC-2.		
Depth(cm) Below Core top	Symbol	Description	Percent Loss On Ignition
0 20		MUD; dusky brn, loose, gooey, w/few small twigs (0-5 cm). PEAT, grayish brn Dense matted fibers 23-29 cm. Grades to mud at base (5-34 cm).	14 7 26.2 49.3 49.0 48 6 57 3 24.3

CORE TS-PC-3	Location: Center of channel, same as TS-DC-3.		
Depth(cm) Below Core top	Symbol	Description	Percent Loss On Ignition
0 20 40		MUD; sandy, dsky yel brn w/abnt twigs wood chunks, few stems(0-6 cm) MUD; dsky yel brn w/ few fibers, dense, clayey 1 mm fiber bed at 11 cm. (6-41 cm)	28.7 23.1 12.2 13.2 12.9 11 3 9.9 11.3 11.3

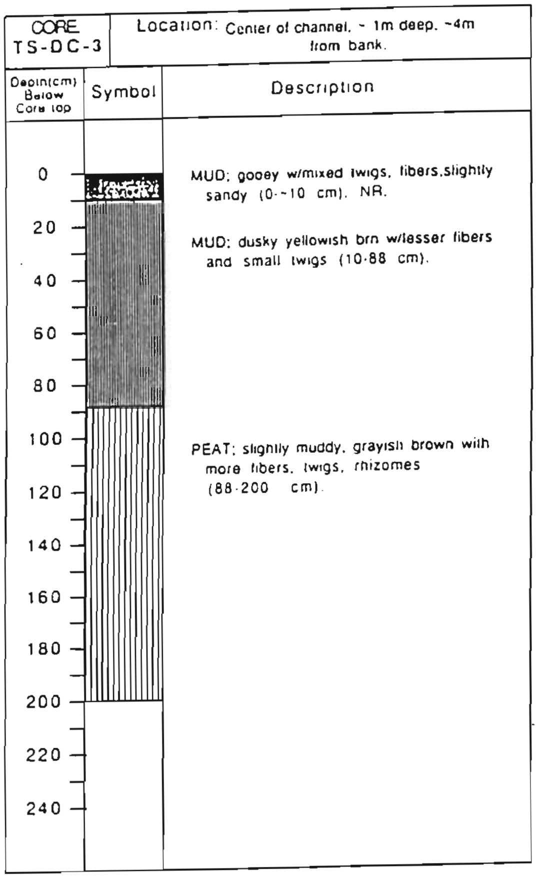
CORE TS-PC-4	Location: Eastern channel margin adjacent to an opening in the marsh.		
Depth(cm) Below Core top	Symbol	Description	Percent Loss On Ignition
0 20		MUD; grayish brn, gooey w/abnt detritus. PEAT; muddy, brnish blk, tightly woven fibers (3-12 cm). MUD; peaty, mod brn w/ abnt matted fibers (12-33 cm).	15.4 59.4 52.4 24.7 18.9 15.6 14.6

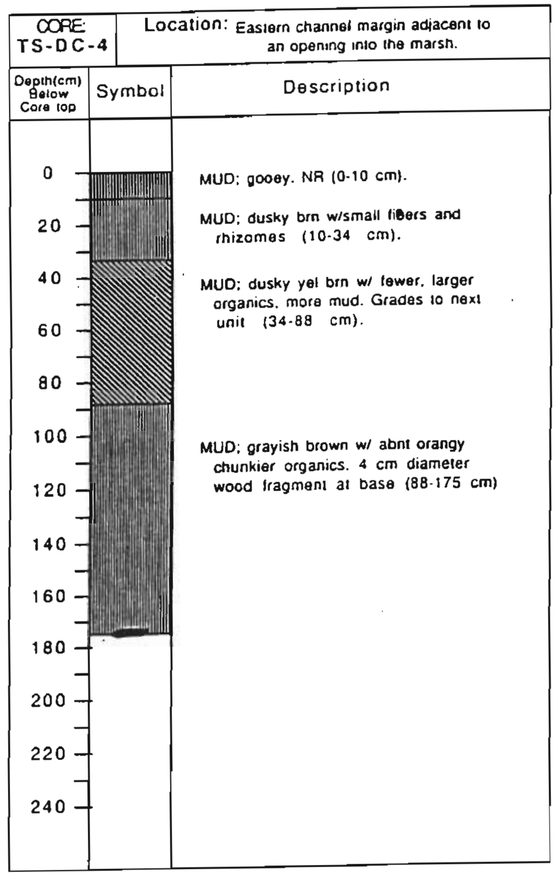
CORE TS-PC-5	Location: On marsh surface ~2m from eastern channel bank.		
Depth(cm) Below Core top	Symbol	Description	Percent Loss On Ignition
0 20		MUD; dsky yel brn w/ matted fibers, rhizomes (0-24 cm).	14.1 12.9 14.9 18.4 13.1

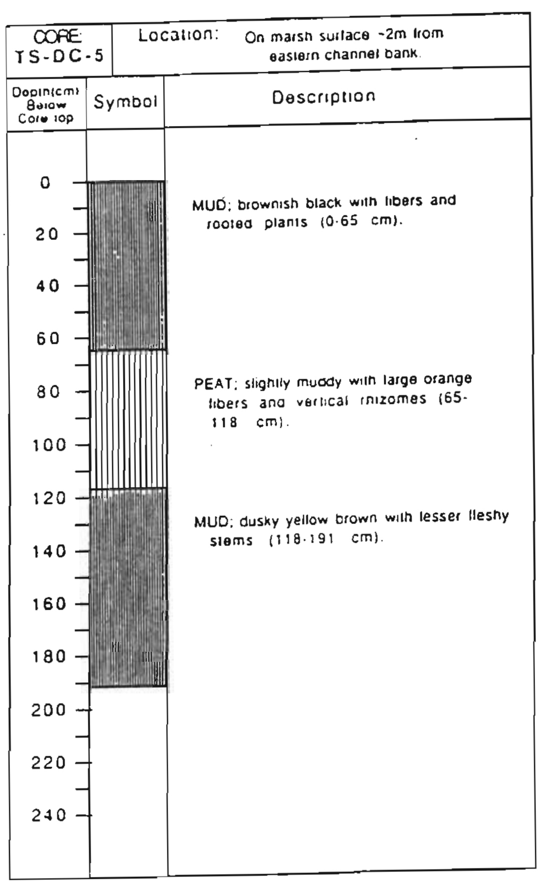
CORE TS-PC-6	Location: Marsh surface at confluence of two streams, site of TS-DC-7 also.		
Depth(cm) Below Core top	Symbol	Description	Percent Loss On Ignition
0 20		MUD; dusky yel brn w/ fibers, rootlets and rhizomes (0-24 cm).	11.6 11.4 10.9 11.5 10.9

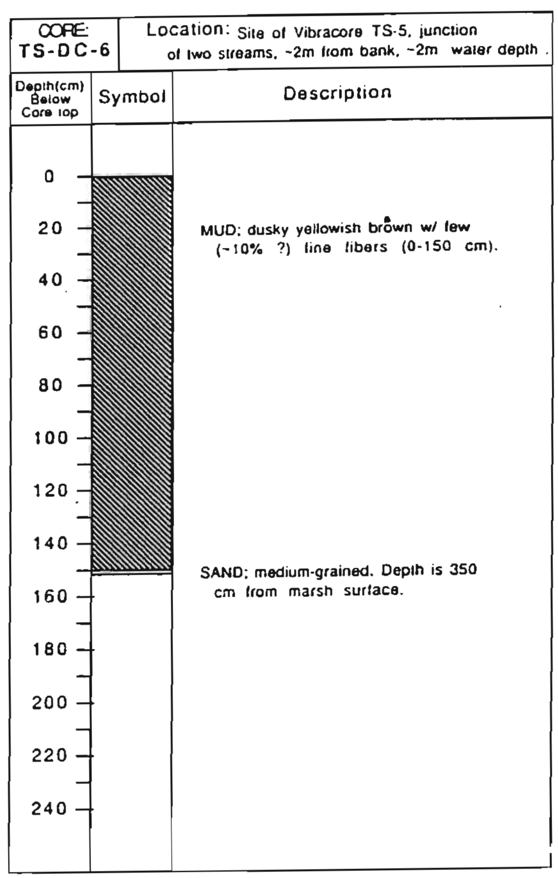
CORE TS-DC-1	Location: Marsh surface on western bank of stream, site of Vibracore TS-1.	
Depth(cm) Below Core top	Symbol	Description
0 20 40 60 80 100 120 140 160 180 200 220 240		MUD; moderate brown w/ rooted plants and fibers (0-10 cm). MUD; dusky yellowish brown w/lesser fibers (10-80 cm). MUD; grayish brown w/ loose organic material (80-122 cm). MUD; dusky yellowish brown with lesser organic fibers (122-192 cm).

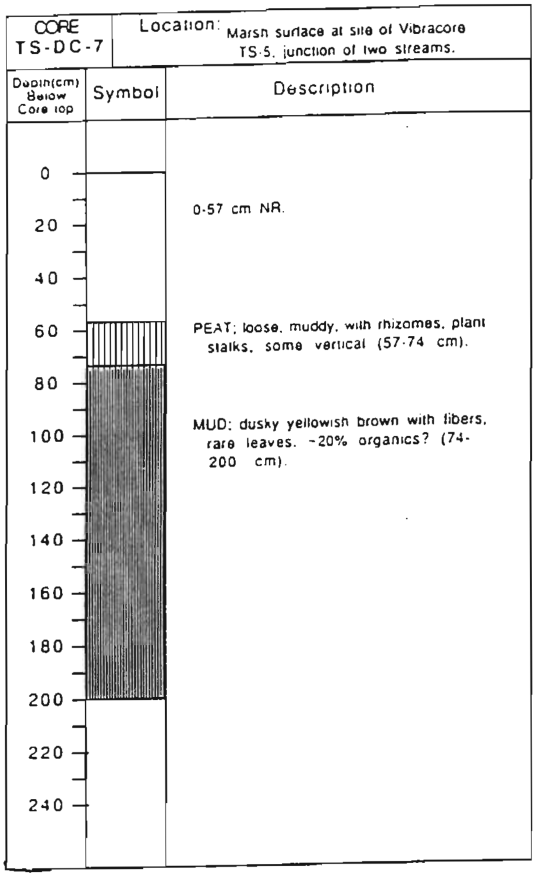
CORE TS-DC-2	Location: In channel 1.8 m from bank at site of TS-DC-1, 89 cm below marsh surface.	
Depth(cm) Below Core top	Symbol	Description
0 20 40 60 80 100 120 140 160 180 200 220 240		MUD; dusky yel brn , gooey w/ few fine fibers, twigs (0-8 cm). PEAT; matted fibers, slightly muddy (8-27 cm) MUD; grayish brn w/abnt fibers .(27-35 cm). MUD; dusky yellowish brn w/ fewer fibers, few beds of darker organics (35-183 cm).

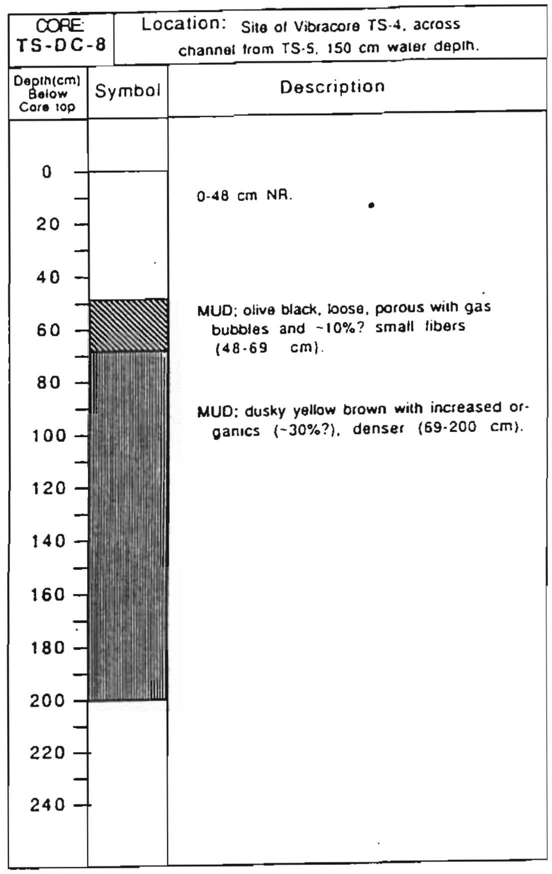

CORE TS-DC-3
Location: Center of channel, ~ 1m deep, ~4m from bank.
Depth(cm) Below Core top
Symbol
Description
0
20
40
60
80
100
120
140
160
180
200
220
240
MUD; gooey w/mixed twigs, fibers,slightly sandy (0-~10 cm). NR.
MUD; dusky yellowish brn w/lesser fibers and small twigs (10-88 cm).
PEAT; slightly muddy, grayish brown with more fibers, twigs, rhizomes (88-200 cm).


CORE TS-DC-4
Location: Eastern channel margin adjacent to an opening into the marsh.
Depth(cm) Below Core top
Symbol
Description
0
20
40
60
80
100
120
140
160
180
200
220
240
MUD; gooey. NR (0-10 cm).
MUD; dusky brn w/small fibers and rhizomes (10-34 cm).
MUD; dusky yel brn w/ fewer, larger organics, more mud. Grades to next unit (34-88 cm).
MUD; grayish brown w/ abnt orangy chunkier organics. 4 cm diameter wood fragment at base (88-175 cm)


CORE TS-DC-5
Location: On marsh surface ~2m from eastern channel bank.
Depth(cm) Below Core top
Symbol
Description
0
20
40
60
80
100
120
140
160
180
200
220
240
MUD; brownish black with fibers and rooted plants (0-65 cm).
PEAT; slightly muddy with large orange fibers and vertical rhizomes (65-118 cm).
MUD; dusky yellow brown with lesser fleshy stems (118-191 cm).


CORE TS-DC-6
Location: Site of Vibracore TS-5, junction of two streams, ~2m from bank, ~2m water depth.
Depth(cm) Below Core top
Symbol
Description
0
20
40
60
80
100
120
140
160
180
200
220
240
MUD; dusky yellowish brown w/ few (~10% ?) fine fibers (0-150 cm).
SAND; medium-grained. Depth is 350 cm from marsh surface.


CORE TS-DC-7
Location: Marsh surface at site of Vibracore TS-5, junction of two streams.
Depth(cm) Below Core top
Symbol
Description
0
20
40
60
80
100
120
140
160
180
200
220
240
0-57 cm NR.
PEAT; loose, muddy, with rhizomes, plant stalks, some vertical (57-74 cm).
MUD; dusky yellowish brown with fibers, rare leaves, ~20% organics? (74-200 cm).


CORE TS-DC-8
Location: Site of Vibracore TS-4, across channel from TS-5, 150 cm water depth.
Depth(cm) Below Core top
Symbol
Description
0
20
40
60
80
100
120
140
160
180
200
220
240
0-48 cm NR.
MUD; olive black, loose, porous with gas bubbles and ~10%? small fibers (48-69 cm).
MUD; dusky yellow brown with increased organics (~30%?), denser (69-200 cm).

APPENDIX VI

Pollen and Seed Taxa in Wetland Cores

Alphabetical Listing of Taxa for Each Core

CORE DC-3

Angiosperms (Flowering plants):

Acer (Maple)
Acnida sp. (Water hemp)
Alnus (Alder)
Alnus serrulata (Common alder)
Ambrosia (Ragweed)
Betula (Birch),
Bidens laevis (Bur-marigold)
Carex (Sedge)
Carya (Hickory)
Castanea (Chestnut)
Cicuta maculata (Water hemlock)
Chenopodium (Pigweed)
Cornus ammmonum (Silky dogwood)
Cyperaceae (Sedge family)
Dulichium sp. (Sedge)
Eleocharis sp. (Spike-rush)
Ericaceae (Blueberry family)
Eupatorium sp. (Thoroughwort)
Fagus (Beech)
Fraxinus (Ash)
Gramineae (Grass family)
Ilex (Holly)
Juglans (Walnut)
Kalmia angustifolia (Lambkill)
Liquidambar (Sweet gum)
Najas gracillima (Naiad)
Nympheaceae (Water lily family)
Nyssa (Black gum, Tupelo)
Platanus (Sycamore)
Polygonum punctatum (Water smartweed)
Polygonum arifolium (Tearthumb)
Potamogeton sp. (Pondweed)
Prunus (Cherry)
Rosa palustris (Marsh rose)
Rubus sp. (Bramble)
Scirpus validus (Soft-stem bulrush)
Scirpus sp. (Bulrush)
Sagittaria sp. (Arrowhead)
Salix (Willow)
Solidago (Goldenrod)

Angiosperms (Flowering plants) continued:

Sparganium (Burreed)
Stellaria (Chickweed)
Thalictrum (Meadow-rue)
Typha (Cattail)
Vaccinium sp. (Blueberry)
Viburnum dentatum (Southern arrowwood)
Viburnum sp. (Arrowwood)
Zizania (Wild rice)

Conifers (Evergreens):

Cupressaceae (Juniper, Bald cypress, etc.)
Pinus rigida (Pitch pine)
Pinus (Pine)
Tsuga (Hemlock)

Pteridophytes (Ferns and Fern allies):

Osmunda (Flowering fern; Cinnamon fern)
Pteridium (Bracken fern)
Lycopodium (Club-moss)

Mosses:

Sphagnum

(Latin name followed by common name in parentheses)

APPENDIX VI: continued

CORE LR-1

Angiosperms (Flowering plants):

Acer (Maple)
Alnus (Alder)
Ambrosia (Ragweed)
Betula (Birch)
Carya (Hickory)
Castanea (Chestnut)
Chenopodium (Pigweed)
Cyperaceae (Sedge family)
Ericaceae (Blueberry family)
Fagus (Beech)
Fraxinus (Ash)
Gramineae (Grass family)
Ilex (Holly)
Juglans (Walnut)
Liquidambar (Sweet gum)
Nympheaceae (Water lily family)
Nyssa (Black gum)
Plantago (Plantain)
Platanus (Sycamore)
Prunus (Cherry)
Sagittaria (Arrowhead)
Salix (Willow)
Solidago (Goldenrod)
Sparganium (Burreed)
Stellaria (Chickweed)
Typha (Cattail)
Thalictrum (Meadow-rue)
Ulmus (Elm)
Umbelliferae (Parsley family)
Viburnum (Arrowwood)
Vitis (Grape)
Zizania (Wild rice)

Conifers (Evergreens):

Cupressaceae (Juniper, Bald cypress, etc.)
Pinus (Pine)
Tsuga (Hemlock)

Pteridophytes (Ferns and Fern allies):

Lycopodium (Club-moss)
Osmunda (Flowering fern)
Pteridium (Bracken fern)

Mosses:

Sphagnum

APPENDIX VI: continued

CORE SJC-3

Angiosperms (Flowering plants):

Acer (Maple)
Alnus (Alder)
Alnus serrulata (Common alder)
Ambrosia (Ragweed)
Betula (Birch)
Bidens laevis (Bur-marigold)
Carex (Sedge)
Carya (Hickory)
Castanea (Chestnut)
Cephalanthus occidentalis (Button bush)
Cicuta maculata (Water hemlock)
Chenopodium (Pigweed)
Cyperaceae (Sedge family)
Dulichium sp. (Sedge)
Eleocharis sp. (Spike-rush)
Ericaceae (Blueberry family)
Eupatorium sp. (Thoroughwort)
Fagus (Beech)
Fraxinus (Ash)
Gramineae (Grass family)
Ilex (Holly)
Juglans (Walnut)
Kalmia angustifolia (Lambkill)
Leersia oryzoides (Rice-cutgrass)
Liquidambar (Sweet gum)
Magnolia (Magnolia)
Najas gracillima (Naiad)
Nympheaceae (Water lily family)
Nyssa (Black gum)
Phragmites sp. (Reed)
Platanus (Sycamore)
Polygonum punctatum (Water smartweed)
Polygonum arifolium (Tearthumb)
Potamogeton diversifolius (Pondweed)
Prunus (Cherry)
Rhyncospora sp. (Sedge)
Rosa palustris (Marsh rose)
Rumex verticillata (Swamp dock)
Scirpus sp. (Bulrush)
Sagittaria latifolia (Arrowhead)
Salix (Willow)
Solidago (Goldenrod)
Sparganium (Burreed)
Stellaria (Chickweed)
Typha (Cattail)
Thalictrum (Meadow-rue)
Viburnum (Arrowwood)
Zannichellia palustris (Horned pondweed)
Zizania (Wild rice)

Conifers (Evergreens):

Cupressaceae (Juniper, Bald cypress, etc.)
Pinus (Pine)
Tsuga (Hemlock)

Pteridophytes (Ferns and Fern allies):

Lycopodium (Club-moss)
Osmunda (Flowering fern)
Pteridium (Bracken fern)
Selaginella (Spike moss)

Mosses:

Sphagnum

APPENDIX VII

GLOSSARY

Aboriginal - Prehistoric peoples in North America.

Aeolian - Carried by the wind. For example, sand dunes are aeolian deposits.

Alluvium - Deposits of gravel, sand, and soil which are transported by flowing water.

Archaeology - The study of the people of the past through the recovery and analysis of the artifacts and other material left behind and context of the finds.

Artifact - Any object shaped or modified by humans,or as aresult of human activity.

Base camp - A prehistoric dwelling site for hunter-gatherers from which resource procurement forays are made.

Bay/basin feature - Also known as whale wallows,these shallow ponds,thought to have been formed at the end of the Pleistocene,were favored locations for prehistoric settlement.

Boreal - Northern forests and tundra.

B.P. - Years before present, relative to A.D. 1950 — the zero year for radiocarbon dating.

Catchment - The area surrounding an archaeological site from which resources were obtained. Also, a drainage basin - the area that feeds a stream.

Cenozoic - The latest of four eras into which geological time is divided. The Cenozoic extends from the end of the Mesozoic up to the present time.

Colluvium - A loose deposit of rock or soil debris accumulated at the base of a cliff or slope.

Columbia Formation - The name given to a particular group of sediment bodies that cover the Upper Coastal plain of northern Delaware.

Chronostratigraphic - Pertaining to geologic time, or geologic time intervals.

Culture - The non-biological mechanism of human adaptation, and the customs, manners, and traditions of a particular society.

Deciduous - Leaf bearing trees that shed in autumn.

Deglaciation - The melting of glaciers or ice sheets.

Detrital - Formed by detritus.

Detritus - Loose fragments, particles, or grains of material. Disintegrated matter, or debris.

Diagenesis - Physical and chemical processes that turn sediment into consolidated rock.

Diagnostic - Distinctive artifacts with characteristic traits that identify a specific time period in the past.

Diatoms - Microscopic, single-celled plants that live in marine or fresh water. Diatoms secrete siliceous bodies with a great variety of shapes that accumulate in sediments.

Ecofact - The non-artifactual remains found in archaeological sites, such as seeds, bones, and plant remains.

Ecotone - The transition zone between ecological communities; for example, the border between grassland and forest.

Edaphic factors - The physical, chemical, and biological characteristics of the soil and local environment.

Eijkelkamp core - A particular brand of sediment coring device made by a company in Denmark.

Emergent - A plant that grows up through water into the air.

Estuary - A partially-enclosed coastal body of water where salt water and fresh water mix due to currents and tides.

Facie - A body of rock or sediment distinguished from others by appearance, composition, or mode of deposition.

Fall line- A transition zone from the Piedmont Uplands to the flatter Coastal Plain, where rivers flow becomes more sluggish and rapids end.

Feature - Any soil disturbance or discoloration that reflects human activity, or an artifact that, is too large to remove from a site; for example, house or storage pits. A feature can also be a very dense cluster of artifacts; for example, a lithic chipping feature.

Flocculation - The process in which particles of sediment aggregate to form small lumps.

Floodplain - That part of a river valley, adjacent to the river channel, that is covered with water when the river overflows its banks during floods.

Flotation - The recover of tiny plant and bone fragments from archaeological deposits using liquid suspension. Also refers to very small artifacts recovered on fine screens during flotation.

Fluvial - Produced by the action of flowing water.

Fossil - The remains or traces of animals or plants that lived in the past which have been preserved by natural processes. Does not include material from historical times.

Fungal hyphea - Cell tubes that form the underground portion of mushrooms and other fungi.

Geomorphology - The study of land forms.

Herbaceous - Having the characteristics of an herb - a plant without a persistent woody stem.

Hiatus - A gap in a sediment sequence due to a lack of deposition, or erosion.

Historic - The time period after the appearance of written records. In North America, the Historic period generally begins with European colonization about A.D. 1600.

Holocene- The latest epoch of the Quaternary geological period,that began 10,000 B.P. The Holocene epoch is preceded by the Pleistocene epoch and includes the present.

Hydrology - The scientific study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Hydrophyte - A plant that grows in, and is adapted to, an aquatic or very wet environment.

Illuviation - The movement of colloids, soluble salts, and mineral particles (clay) down through a soil profile through the leaching action of water.

In situ - In the original place of deposition.

Interface- The boundary between two bodies or spaces.

Isostatic rebound - Upward movement of the earth's crust following the removal of a load, such as a glacier.

Lacustrine - Of, or pertaining to a lake environment.

Laminae - Thin layers of sediment less than 1.0 mm thick.

Landsat satellite - Satellite placed in orbit around the earth to obtain photographs of the earth's surface for scientific study.

Lithic - Pertaining to, or consisting of rock or stone.

Lithology - The physical characteristics of a rock, or sediment body.

Loam - A loose soil composed of roughly equal parts of silt, clay, and sand, often containing organic matter, as well. Usually very fertility and conducive to plant growth.

Locus - A clearly-defined archaeological site or testing location.

Loss-on-ignition - An analytical technique to determine the percent of organic matter within a sample of soil or sediment. A small quantity of dry material is carefully weighed, heated to 500 degrees Celsius for four hours, and then weighed again. All organic mater is burned off in the process.

Macro-band base camp- An archaeological site one hectare or larger in area characterized by a wide variety of tool types,abundant ceramics, semi-subterranean house structures, storage pit features,and abundant debitage from tool manufacture and reduction.

Macrophyte - A macroscopic plant (visible to the naked eye) in an aquatic environment.

Marine - Ocean or sea water; salt water environments.

Marl - Calcareous clay, usually a lake deposit.

Megafauna - Large extinct mammals, including mammoths and mastodons, that lived during the last ice age.

Mesic forest - A forest of relatively, wet-adapted plant species, such as hemlock forests.

Mesozoic - One of the great divisions of geologic time; follows the Paloezoic era and precedes the Cenozoic era.

Micro-band- A component of macro-band, perhaps one or two extended families, that periodically operate independently of the macro-band group.

Microenvironment - A small scale environment; part of a larger ecological community. For example, a floodplain with sycamore trees within a deciduous forest dominated by oaks, beech, and tulip tree.

Morphology - Observations on the shape of land; or the study of the form or structure of organisms.

Morphometry - Measurements of shape.

Oxidation - Chemical reaction between oxygen and other substances.

Paleobotanical - Pertaining to old, or fossil, plant material.

Paleoecology - The science of the relationship between ancient organisms and their environments.

Paleoenvironment - An environment of the past (which may have no modern analog).

Paleogeography - The geography of an area in the past. The study of past geography.

Paleohydrology - The hydrology of an area in the past. The study of past hydrology.

Palustrine - Pertaining to material deposited in a swamp environment.

Palynology - The scientific study of pollen and spores.

Pediments - Gently-sloping erosional surfaces between mountains and valleys.

Pedogenic - Pertaining to soil development.

Periglacial - An area, process, or conditions close to the margin of a glacier or ice sheet.

Physiographic zone - Regions or areas that are characterized by a particular geography, geology, and topography.

Piedmont region - An area of gently rolling to hilly land lying between the Appalachian Mountains and the Atlantic Coastal Plain. The division between the Piedmont region and the Coastal Plain is marked by the Fall Line.

Plant macrofossil - Larger fragments or pieces of ancient, or fossilized plant material.

Pleistocene - One of two divisions of the Quaternary geological period, which began 1.6 million years ago. The Pleistocene is characterized by the "Ice Ages" in which large ice sheets covered high latitudes of the earth. Followed by the Holocene epoch.

Pollen - The fine, powder-like material that is the male element of flowering plants.

Pollen signal - The pollen assemblage that results from all of the pollen-producing plants in an area at a particular time.

Prehistoric - The archaeological time period before the appearance of written records. In the New World, prehistoric generally refers to indigenous, non-European societies.

Primary lithic resource - Outcrops of workable stone that are found within the matrix of their original formation.

Procurement site - A place that is visited because there is a particular item to acquire in the vicinity; i.e., a wetland where edible wild foods are known to grow.

Projectile point - Strictly speaking, a biface attached to the head of an airborne item of weaponry, like an arrow or a thrown dart. In general usage, refers to any biface.

Quarry site - An archaeological site located at either a primary or secondary outcrop of lithic material used in the manufacture of stone tools.

Quarry reduction station - A place where material obtained from a quarry, such as large flakes, cores and very early stage bifaces were taken for further reduction into smaller primary-thinned bifaces.

Quaternary - The latest period of the Cenozoic geological era. Includes two epochs - the earlier Pleistocene from 1.6 million B.P. to 10,000 B.P., and the Holocene from 10,000 B.P. to the present.

Rhythmites - Layers of sediment laid down in a regular sequence. For example, alternating bands of sediment deposited in a lake by seasonal fluctuations of water temperature and stream flow.

Riparian - Pertaining to the banks of a body of water.

Rip-up clast - A chunk of sediment moved, or disturbed, so that it is out of sequence. Evidence of erosion or root disturbance.

Riverine - Of, or pertaining to a river.

Secondary lithic resource - Cobbles and boulders of variable size that have been removed from the matrix of their original formation, transported by alluvial or glacial agents, and redeposited at a new location which may be quite distant from their original source.

Sediment - Solid material, either mineral or organic, that has been moved from its place of origin by wind, water, or ice, and has come to rest on the earth's surface either above or below sea level.

Semidiurnal tides - Tides that usually occur twice a day.

Site - A place with evidence of human occupation.

Soilhorizon- Soils are classified into three (A, B, and C) horizons,due to different kinds of chemical and physical processes.

Sponge spicules - Microscopic siliceous spines that form within the tissues of fresh water and marine sponges.

Staging site - A temporary camp where preparations are made for another operation, such as a hunting foray.

Stratigraphy - Thestudy of sediment layers. Also, refers to the sequence of strata at a particular locality. The characteristics of each individual stratum and its relationship to other strata in the sequence is critical to understanding the temporal and spatial characteristics of the site.

Strata - The various layers of soils or sediments of human or geological origin which comprise archaeological sites.

Synchronic - Referring to a single period in time.

Taxa - Plural of taxon. Named groups of organisms.

Taxon - A named group of organisms; for example, a species of animal.

Thermokarst - Settling or caving of the ground due to the melting of ice in the ground.

Tidal range - The vertical distance between high tide and low tide.

Tool kit - A collection of artifacts interpreted as being designed for a specific task.

Topography - The physical surface features and configuration of land.

Transgressive environment - An environment undergoing a sea-level transgression. Sea-level rise causes water to over-ride the landscape so that environmental zones are pushed in land.

Vibracore - A core obtained by vibracoring.

Vibracoring - A technique of sediment coring that uses a motorized concrete smoother for use as a vibrator to force a metal coring tube down into sediments. Vibracoring avoids several problems encountered in other methods of coring.

Wetland - Marshs, swamps, bogs, or other wet ecosystems characterized by plants adapted to growth in saturated soils or standing water.

Xeric Forest - A forest characterized by plants adapted to dry conditions, such as grasslands and forests of oak and hickory.

Xerophyte - A plant that grows in arid conditions.

Note: Many of the definitions above were taken from the "Dictionary of Geological Terms" published by the American Geological Institute (Towbridge 1962).